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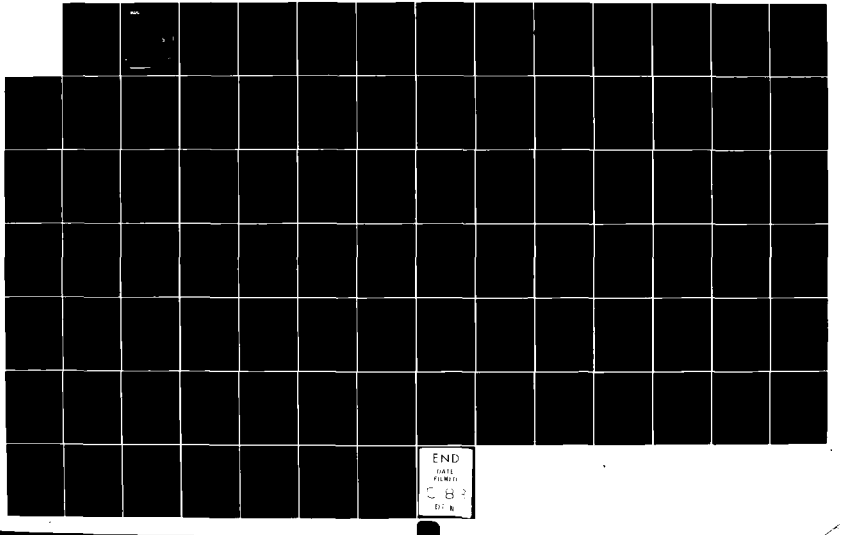

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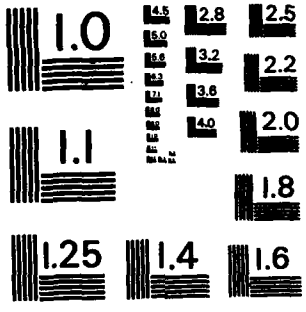

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SDC
System Development Corporation
2500 Colorado Avenue, Santa Monica, CA 90406, Telephone (213) 820-4111

series base no./vol./release
TM- 7172/481/00
author
Technical Staff
technical
Carl M. Switzky
release
Gerald D. Cole
for
Charles A. Savant
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ABSTRACT

This document specifies the Internet Protocol (IP) which supports the interconnection of communication subnetworks. The document includes an introduction to IP with a model of operation, a definition of services provided to users, and a description of the architectural and environmental requirements. The protocol service interfaces and mechanisms are specified using an abstract state machine model.

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This document specifies the Internet Protocol (IP) which supports the interconnection of communication subnetworks. The document includes an introduction to IP with a model of operation, a definition of services provided to users, and a description of the architectural and environmental requirements. The protocol service interfaces and mechanisms are specified using an abstract state machine model.

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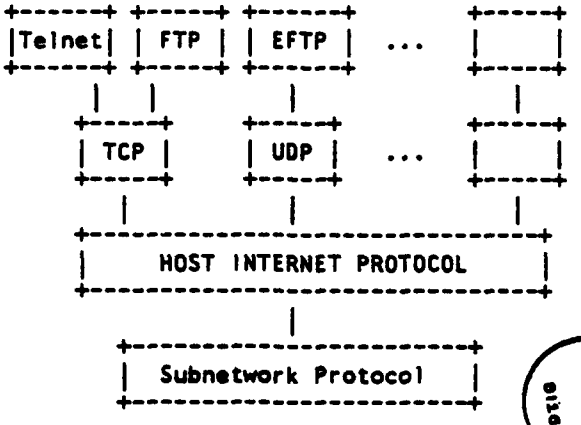
CONTENTS

1. OVERVIEW

This document specifies the Internet Protocol (IP) which supports the interconnection of communication subnetworks. The document introduces the Internet Protocol's role and purpose, defines the services provided to users, and specifies the mechanisms needed to support those services. This document also defines the services required of the lower protocol layer, describes the upper and lower interfaces, and outlines the execution environment services needed for implementation. In addition, a glossary of terms and a set of appendices discussing related issues of IP are included. The reader is assumed to be familiar with the DCEC Architecture Report which presents the proposed protocol architecture model for DoD communication services[14]. This specification incorporates the organization and specification techniques presented in the Protocol Specification Report[15].

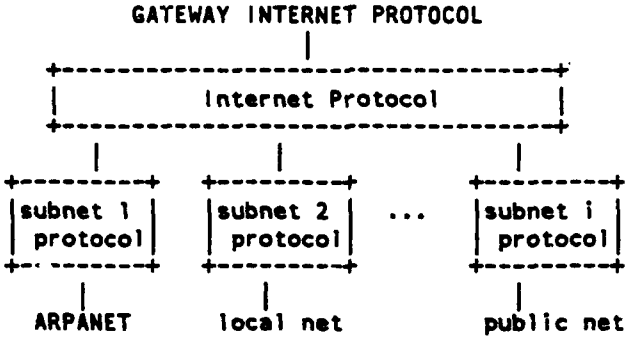
The Internet Protocol is designed to interconnect packet-switched communication subnetworks to form an internetwork. IP transmits blocks of data, called internet datagrams, from sources to destinations throughout the internet. Sources and destinations are hosts located on either the same subnetwork or connected subnetworks. IP is purposely limited in scope to provide the basic functions necessary to deliver a block of data. Each internet datagram is an independent entity unrelated to any other internet datagram. IP does not create connections or logical circuits. IP has no mechanisms to promote data reliability, flow control, sequencing, or other services commonly found in virtual circuit protocols.



1. Example Host Protocol Hierarchy

This document specifies a host IP. As defined in the DoD architectural model, the Internet Protocol resides in the upper sublayer of the network layer. Thus, IP provides services to transport layer protocols and relies on the services of the lower network sublayer protocol. In each gateway (a system interconnecting two or more subnets) an IP resides above two or more subnetwork protocol entities. In a gateway, IP is closely coupled to the Gateway to

Gateway Protocol (GGP) [19] to form a gateway IP. A gateway IP supports many of the same functions as a host resident IP, but provides additional services such as maintenance of current internet topology data. Throughout the remainder of the document, a host resident IP is simply referred to as IP.



2. Example Gateway Protocol Hierarchy

A protocol in an upper layer passes data to IP for delivery. IP packages the data as an internet datagram and passes it to the local subnetwork protocol for transmission across the local subnet. If the destination host is on the local subnet, IP sends the datagram through the subnet directly to that host. If the destination host is on a foreign subnet, IP sends the datagram to a local gateway. The gateway, in turn, sends the datagram through the next subnet to the destination host, or to another gateway.

Thus, datagrams move from one IP module to another through an interconnected set of subnetworks until they reach their destinations. The sequence of IP modules handling the datagram in transit is called the gateway route. The gateway route is distinct from the lower level node-to-node route supplied by a particular subnetwork. The gateway route is based on the destination internet address. The IP modules share common rules for interpreting internet addresses to perform internet routing.

Occasionally, a gateway IP or destination IP will encounter an error during datagram processing. Such errors and their report formats are specified in the Internet Control Message Protocol (ICMP). Although specified as a separate unit, ICMP is is actually an integral part of IP to be implemented in every IP module.

In transit, datagrams may traverse a subnetwork whose maximum packet size is smaller than the size of the datagram. To handle this condition, IP provides fragmentation and reassembly mechanisms. The gateway at the smaller-packet subnet fragments the original datagram into pieces, called datagram fragments, that are small enough for transmission. The IP module in the destination host reassembles the datagram fragments to reproduce the original datagram.

IP can support a diverse set of upper layer protocols (ULPs). A transport protocol with real-time requirements, such as the Network Voice Protocol (NVP), can make use of IP's datagram service directly. A transport protocol providing ordered reliable delivery, such as TCP [16], can build additional mechanisms on top of IP's basic datagram service. Also, IP's delivery service can be customized in some ways to suit the special needs of an upper layer protocol. For example, a predefined gateway route, called a source route, can be supplied for an individual datagram. Each IP module forwards the datagram according to the source route in addition to using the standard routing mechanism.

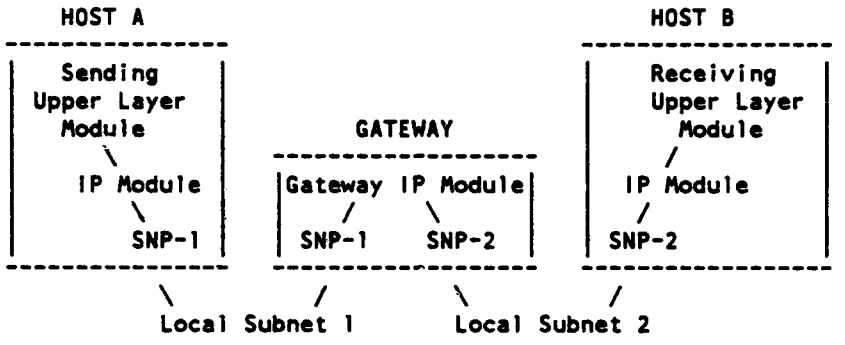
The current Internet Protocol evolved from ideas suggested in [2], and from proposals within the International Federation for Information Processing (IFIP) Technical Committee 6.1, in which internet functions and reliable transport functions were combined in a single protocol. Subsequent development of other upper level protocols (such as packet speech) led to separation of these function to form IP [6] and the Transmission Control Protocol [7].

A brief discussion of the major design tradeoffs motivating IP's current form appears in [8]. Other approaches to internetting, including the CCITT Recommendation X.75 and the PUP architecture developed by the Xerox Corporation, are introduced in [1 & 4], and compared in [13 & 20]. A wide range of technical, legal, and political issues associated with subnetwork interconnection is presented in [3]. Certain aspects of fragmentation and routing are are discussed in [17 & 18]. [1,3,9-11,13,17 & 18] contain current address mappings, service mappings, and assigned numbers used in DARPA internetwork implementations.

1.1 SCENARIO

The following scenario illustrates the model of operation for transmitting a datagram from one upper layer protocol to another. The scenario is purposely simple so that IP's basic operation is not obscured by the details of interface parameters or header fields.

A ULP in host A is to send data to its peer protocol in host B on another subnetwork. In this case, the source and destination hosts are on subnetworks directly connected by a gateway.

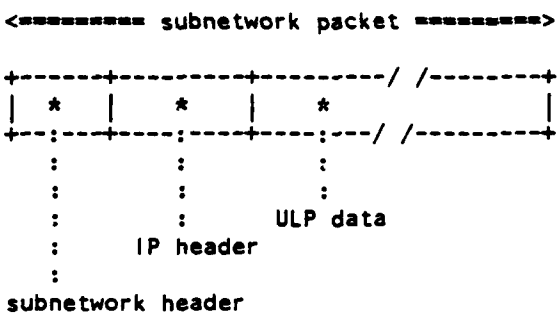


Basic Model of Operation

a. The sending ULP passes its data to the IP module, along with the destination internet address and other parameters.

b. The IP module prepares an IP header and attaches the ULP's data to form an internet datagram. Then, the IP module determines a local subnetwork address from the destination internet address. In this case, it is the address of the gateway to the destination subnetwork. The internet datagram along with the local subnet address is passed to the local subnetwork protocol (abbreviated as SNP).

c. The SNP creates a local subnetwork header and attaches it to the datagram forming a subnetwork packet. The SNP then transmits the packet across the local subnet.



d. The packet arrives at the gateway connecting the first and second subnetworks. The SNP of the first subnet strips off the local subnetwork header and passes the remainder to the IP module.

e. The IP module determines from the destination internet address in the IP header that the datagram is intended for a host in the second subnet. The IP module then derives a local subnetwork address for the destination host. That address is passed along with the datagram to the SNP of the second subnetwork for delivery.

f. The second subnet's SNP builds a local subnetwork header and appends the datagram to form a packet for the second subnetwork. That packet is transmitted across the second subnet to the destination host.

g. The SNP of the destination host strips off the local subnetwork header and hands the remaining datagram to the IP module.

h. The IP module determines that the datagram is bound for a ULP within this host. The data portion of the datagram and information from the IP header are passed to the ULP.

Delivery of data across the internet is complete.

2. SERVICES PROVIDED TO UPPER LAYER

This section describes the services offered by the Internet Protocol to upper layer protocols (ULPs). The goals of this section are to provide the motivation for protocol mechanisms and a definition of the functions provided by this protocol.

The services provided by IP are:

- o internet datagram service
- o virtual network service
- o error reporting service

A description of each service follows.

2.1 DATAGRAM SERVICE

The Internet Protocol shall provide a datagram service between homogeneous upper layer protocols in an internet environment. A datagram service is characterized by data delivery to the destination with non-zero probability; some data may possibly be lost. Also, a datagram service does not necessarily preserve the sequence in which data is supplied by the source upon delivery at the destination.

IP shall deliver received data to a destination ULP in the same form as sent by the source ULP. IP shall discard datagrams when insufficient resources are available for processing. IP does not detect datagrams lost or discarded by the subnetwork layer.

As part of the delivery service, IP insulates upper layer protocols from subnetwork specific characteristics. For example, IP maps internet addresses supplied by ULPs into local addresses used by the local subnetwork. Also, IP hides any packet-size restrictions of subnetworks along the transmission path within the internet.

2.2 GENERALIZED NETWORK SERVICES

IP shall provide to upper layer protocols the ability to select virtual network service parameters. IP shall provide a general command set for the ULPs to indicate the services desired. Thus, the ULPs can tune certain properties of IP and the underlying subnetworks to customize the transmission service according to their needs.

The virtual network parameters fall into two categories: service quality parameters and service options. Service quality parameters influence the transmission service provided by the subnetworks; service options are additional functions provided by IP. A brief description of each follows:

o Service Quality Parameters

- Precedence : attempts preferential treatment for high importance datagrams
- Transmission Mode : datagram vs. stream. Stream mode attempts to minimize delay and delay dispersion through reservation of network resources
- Reliability : attempts to minimize data loss and error rate
- Speed : attempts prompt delivery
- Resource Tradeoff : indicates relative importance of speed vs. reliability.

o Service Options

- Security Labelling : identifies datagram for compartmented hosts
- Source Routing : selects set of gateway IP modules to visit in transit
- Route Recording : records gateway IP modules encountered in transit
- Stream Identification : names reserved resources used for stream service
- Time Stamping : records time information
- Don't Fragment : marks a datagram as an indivisible unit

2.3 ERROR REPORTING SERVICE

IP shall provide error reports to the upper layer protocols indicating errors detected in providing the above services. In addition, certain errors detected by lower layer protocols or supplied in ICMP messages shall be passed to the ULPs. These reports indicate several classes of errors including invalid arguments, insufficient resources, and transmission errors. The errors that IP must report to ULPs are to be determined for each implementation.

3. UPPER LAYER SERVICE/INTERFACE SPECIFICATION

This section specifies the IP services provided to upper layer protocols and the interface through which these services are accessed. The first part defines the interaction primitives and interface parameters for the upper interface. The second part contains the abstract machine specification of the upper layer services and interaction discipline.

3.1 INTERACTION PRIMITIVES

An interaction primitive defines the purpose and content of information exchanged between two protocol layers. Primitives are grouped into two classes based on the direction of information flow. Information passed downward, in this case from a ULP to IP, is called a service request primitive. Information passed upward, in this case from IP to a ULP, is called a service response primitive. Interaction primitives need not occur in pairs. That is, a service request does not necessarily elicit a service "response"; a service "response" may occur independently of a service request.

The information associated with an interaction primitive falls into two categories: parameters and data. The parameters describe the data and indicate how the data is to be treated. The data is not examined or modified. The format of the parameters and data is implementation dependent and therefore not specified.

A given IP implementation may have slightly different interaction primitives imposed by the execution environment or system design factors. In those cases, the primitives can be modified to include more information or additional primitives can be defined to satisfy system requirements. However, all IPs must provide at least the interaction primitives specified below to guarantee that all IP implementations can support the same protocol hierarchy.

3.1.1 Service Request Primitives

A single service request primitive supports IP's datagram service, the SEND primitive.

3.1.1.1 SEND The SEND primitive contains complete control information for each unit of data to be delivered. IP accepts in a SEND at least the following information:

- source address - internet address of ULP sending data
- destination address - internet address of ULP to receive data
- protocol - name of the recipient ULP
- type of service indicators - relative transmission quality associated with unit of data

- precedence - one of eight levels : (P0, P1, P2, P3, P4, P5, P6, P7) where P0 <= P1 <= P2 <= P3 <= P4 <= P5 <= P6 <= P7

- reliability - one of two levels : (R0, R1) where R0 <= R1

- delay - one of two levels : (D0, D1) where D0 <= D1

- throughput - one of two levels : (T0, T1) where T0 <= T1

o identifier - value optionally provided by this ULP distinguishing this portion of data from others sent by this ULP.

o don't fragment indicator - flag showing whether IP can fragment data to accomplish delivery

o time to live - The value in seconds which indicates the maximum lifetime of data within the internet. Time_to_live is decremented by one second for each gateway transversed.

o data length - length of data being transmitted

o option data - options requested by ULP from following list: security, loose or strict source routing, record routing, stream identification, or time stamp (Section 6.2.14).

o data - present when data length is greater than zero.

3.1.2 Service Response Primitives
A single service response primitive supports IP's datagram service, the DELIVER primitive.

3.1.2.1 DELIVER The DELIVER primitive contains the data passed by a source ULP in a SEND, along with addressing, quality of service, and option information. IP passes in a DELIVER at least the following information:

o source address - internet address of sending ULP

o destination address - internet address of the recipient ULP

o protocol - name of recipient ULP as supplied by the sending ULP

o type of service indicators - relative transmission quality associated with unit of data

- precedence - one of eight levels : (P0, P1, P2, P3, P4, P5, P6, P7) where P0 <= P1 <= P2 <= P3 <= P4 <= P5 <= P6 <= P7

- delay - one of two levels : (D0, D1) where D0 <= D1

- reliability - one of two levels : (R0, R1) where R0 <= R1

- throughput - one of two levels : (T0, T1) where T0 <= T1

o data length - length of received data (possibly zero)

o option data - options requested by source ULP from following list: security, loose source routing, strict source routing, record routing, stream identification, or time stamps (Section 6.2.14).

o data - present when data length is greater than zero.

In addition, a DELIVER must contain error reports from IP either together with parameters and data listed above, or independently of that information.

3.2 EXTENDED STATE MACHINE SPECIFICATION OF SERVICES PROVIDED TO UPPER LAYER

The extended state machine defines the behavior of the entire service machine from the perspective of the upper layer protocol. An extended state machine definition is composed of a machine instantiation identifier, a state diagram, a state vector, a set of data structures, an event list, and an events and actions correspondence.

3.2.1 Machine Instantiation Identifier

Each upper interface state machine is uniquely identified by the four interaction primitive parameters:

o source address

o destination address

o protocol

o identifier

One state machine instance exists for the SEND and DELIVER primitives whose four parameters carry identical values.

3.2.2 State Diagram

The upper interface state machine has a single state which never changes. No diagram is needed.

3.2.3 State Vector

The upper interface state machine has a single state which never changes. No state vector is needed.

3.2.4 Data Structures

For clarity in the events and actions section, data structures are declared for the interaction primitives and their parameters. A subset of ADA data constructs, common to most high level languages, is used. However, a data structure may be partially typed or completely untyped where specific formats

or data types are implementation dependent.

3.2.4.1 from ULP The from_ULP structure holds the interface parameters and data associated with the SEND primitive specified above. This structure directly corresponds to the from_ULP structure declared in 6.3.4.2 of the mechanism section. The from_ULP structure is declared as:

```
type from_ULP_type is
  record
    source_addr
    destination_addr
    protocol
    type_of_service is
      record
          precedence
          delay
          throughput
          reliability
      end record;
    identifier
    dont_fragment
    time_to_live
    length
    options
    data
  end record;
```

3.2.4.2 to ULP The to_ULP structure holds interface parameters and data associated with the DELIVER primitive, as specified in section 3.1.2 above. This structure directly corresponds to the to_ULP structure declared in 6.3.4.3 of the mechanism specification. The to_ULP structure is declared as:

```
type to_ULP_type is
  record
    source_addr
    destination_addr
    protocol
    type_of_service is
      record
          precedence
          delay
          reliability
          throughput
      end record;
    length
    options
    data
    error
  end record;
```

3.2.5 Event List

The events are drawn from the interaction primitives specified in section 3.1 above. An event is composed of a service primitive and an abstract timestamp to indicate the time of event initiation. The event list:

1. SEND(from_ULP) at time t

2. NULL - Although no service request is issued by a ULP, certain conditions within IP or lower layers produce a service response. These conditions can include duplication of data and subnet errors.

3.2.6 Events and Actions

The following section defines the set of possible actions elicited by each event.

EVENT = SEND(from_ULP) at time t

Actions:

1. DELIVER to_ULP at time t+N to the protocol designated by from_ULP.protocol at destination from_ULP.destination_addr with all of the following properties:

    a. The time elapsed during data transmission satisfies the time-to-live limit, i.e. N <= from_ULP.time_to_live.

    b. The quality of data transmission is at least equal to the relative levels specified by from_ULP.type_of_service.

    c. if (from_ULP.dont_fragment = TRUE) then IP fragmentation has not occurred in transit.

    d. if (from_ULP.options includes loose source routing) then to_ULP.data has visited in transit at least the gateways named by source route provided by SEND.

    e. if (from_ULP.options includes strict source routing) then to_ULP.data has visited in transit only the gateways named by source route provided by SEND.

    f. if (from_ULP.options includes record routing) then the list of nodes visited in transit is delivered in to_ULP.

    g. if (from_ULP.options includes security labelling) then the security label is delivered in to_ULP.

    h. if (from_ULP.options includes stream identifier)

then the stream identifier is delivered in to_ULP.

i. if (from_ULP.options includes internet timestamp)
then the internet timestamp is delivered in to_ULP.

OR,

2. DELIVER to the protocol designated by from_ULP.protocol at source from_ULP.source_addr indicating one of the following error conditions:

a. destination from_ULP.destination_addr unreachable

b. protocol from_ULP.protocol unreachable

c. if (from_ULP.dont_fragment = TRUE)
then fragmentation needed but prohibited

d. if (from_ULP.options contains any option)
then parameter problem with option.

OR,

3. no action

EVENT = NULL

Actions:

1. DELIVER to the protocol designated by from_ULP.protocol at source from_ULP.source_addr indicating the following error condition:

a. error conditions in subnet layer

OR,

2. DELIVER to_ULP at time t+N to the protocol designated by from_ULP.protocol at destination from_ULP.destination_addr with all of the following properties:

a. The time elapsed during data transmission satisfies the time-to-live limit, i.e. N <= from_ULP.time_to_live.

b. The quality of data transmission is at least equal to the relative levels specified by from_ULP.type_of_service.

c. if (from_ULP.dont_fragment = TRUE)
then IP fragmentation has not occurred in transit.

d. if (from_ULP.options includes loose source routing)
then to_ULP.data has visited in transit at least
the gateways named by source route provided in SEND.

e. if (from_ULP.options includes strict source routing)
then to_ULP.data has visited in transit only
the gateways named by source route provided in SEND.

f. if (from_ULP.options includes record routing)
then the list of nodes visited in transit is
delivered in to_ULP.

g. if (from_ULP.options includes security labelling)
then the security label is delivered in to_ULP.

h. if (from_ULP.options includes stream identifier)
then the stream identifier is delivered in to_ULP.

i. if (from_ULP.options includes internet timestamp)
then the internet timestamp is delivered in to_ULP.

4. SERVICES REQUIRED FROM LOWER LAYER

This section describes the minimal services required of the subnetwork layer. The services required are:

- o transparent data transfer between hosts within a subnetwork
- o error reporting

A description of each service follows.

4.1 DATA TRANSFER

The subnetwork layer must provide a transparent data transfer between hosts within a single subnetwork. Only the data to be delivered, and the necessary control and addressing information should be required as input from IP. Intranet routing and subnetwork operation shall be handled by the subnetwork layer itself.

The subnetwork need not be a reliable communications medium. Data should arrive with non-zero probability at a destination. Data may not necessarily arrive in the same order as it was supplied to the subnetwork layer, nor is data guaranteed to arrive error free.

4.2 ERROR REPORTING

The subnetwork layer shall provide reports to IP indicating errors from the subnetwork and lower layers as feasible. The specific error requirements of the subnetwork layer are dependent on the individual subnetworks.

5. LOWER LAYER SERVICE/INTERFACE SPECIFICATION

This section specifies the minimal subnetwork protocol services required by IP and the interface through which those services are accessed. The first part defines the interaction primitives and their parameters for the lower interface. The second part contains the abstract machine specification of the lower layer services and interaction discipline.

5.1 INTERACTION PRIMITIVES

An interaction primitive defines the purpose of information exchanged between two protocol layers. Two kinds of primitives, based on the direction of information flow, are defined. Service requests pass information downward; service responses pass information upward. These primitives need not occur in pairs, nor in a synchronous manner. That is, a request does not necessarily elicit a "response"; a "response" may occur independently of a request.

The information associated with an interaction primitive falls into two categories: parameters and data. The parameters describe the data and indicate how the data is to be treated. The data is not examined or modified. The format of interaction primitive information is implementation dependent and so is not specified.

A given IP implementation may have slightly different interfaces imposed by the nature of the subnetwork or execution environment. Under such circumstances, the primitives can be modified to include more parameters or additional primitives can be defined. However, all IPs must provide at least the interface specified below to guarantee that all IP implementations can support the same protocol hierarchy.

5.1.1 Service Request Primitives

A single service request primitive is required from the SNP, a SNP_SEND primitive.

5.1.1.1 SNP SEND The SNP_SEND contains an IP datagram, a destination, and parameters describing the desired transmission quality. The SNP receives in an SNP_SEND at least the following information:

- o local destination address - local subnetwork address of destination host or gateway
- o type of service indicators - relative transmission quality associated with the datagram
  - precedence - one of eight levels : (P0, P1, P2, P3, P4, P5, P6, P7) where P0 <= P1 <= P2 <= P3 <= P4 <= P5 <= P6 <= P7
  - reliability - one of two levels : (R0, R1) where R0 <= R1
  - delay - one of two levels : (D0, D1) where D0 <= D1

- throughput - one of two levels : (T0, T1) where T0 <= T1

o length - size of the datagram

o datagram

5.1.2 Service Response Primitives
One service response primitive is required to support IP's datagram service, the SNP_DELIVER primitive.

5.1.2.1 SNP_DELIVER The SNP_DELIVER contains only a datagram which is an independent entity containing an IP header and data. An IP receives in an SNP_DELIVER at least the following information:

o datagram

In addition, a SNP_DELIVER may contain error reports from the SNP, either together with a datagram or independently of one.

5.2 EXTENDED STATE MACHINE SPECIFICATION OF SERVICES REQUIRED FROM LOWER LAYER

The extended state machine defines the behavior of the entire service machine with respect to the lower layer protocol. An extended state machine definition is composed of a machine instantiation identifier, a state diagram, a state vector, a set of data structures, an event list, and an events and actions correspondence.

5.2.1 Machine Instantiation Identifier
Each lower interface state machine is uniquely identified by the four values:

o source address

o destination address

o protocol

o identification

These values are drawn from header fields of the datagram passed by the SNP_SEND and SNP_DELIVER primitives. One state machine instance exists for the interaction primitives whose parameters carry the same values.

5.2.2 State Diagram
The lower interface state machine has a single state which never changes. No diagram is needed.

5.2.3 State Vector
No state vector is needed for the lower interface state machine.

5.2.4 Data Structures
For clarity in the events and actions section, data structures are declared for the interaction primitives and their parameters. These structures are declared in a subset of ADA composed of constructs common to most high level languages. However, a data structure may be partially typed or completely untyped where specific formats or data types are implementation dependent.

5.2.4.1 from SNP The from_SNP structure holds the interface parameters and datagram associated with the SNP_DELIVER primitive, as specified in section 5.1.2.1 This structure directly corresponds to the from_SNP structure declared in section 6.3.4.4 of the mechanism specification. The from_SNP structure is declared as:

```
type from_SNP_type is
  record
     source_destination_addr
     dtgm: datagram_type;
     error
  end record;
```

The dtgm element is itself a structure as specified below.

5.2.4.2 to SNP The to_SNP structure holds the data and parameters associated with the SNP_SEND primitive specified in section 5.2.1. This structure directly corresponds to the to_SNP structure declared in section 6.3.4.5 of the mechanism specification. The to_SNP structure is declared as:

```
type to_SNP_type is
  record
    local_destination_addr
    type_of_service_indicators
    length
    dtgm: datagram_type;
  end record;
```

The dtgm element is itself a structure as specified below.

5.2.4.3 dtgm The dtgm structure holds a datagram made up of a header portion and a data portion as specified in section 6.2. A dtgm structure is declared as:

```
type datagram_type is
   record
     version : HALF_OCTET;
     header_length : HALF_OCTET;
     type_of_service : OCTET;
     total_length : TWO_OCTETS;
```

```
        identification : TWO_OCTETS;
        dont_frag_flag : BOOLEAN;
        more_frag_flag : BOOLEAN;
        fragment_offset : ONE_N_FIVE_EIGHTHS_OCTETS;
        time_to_live : OCTET;
        protocol : OCTET;
        header_checksum : TWO_OCTETS;
        source_addr : FOUR_OCTETS;
        destination_addr : FOUR_OCTETS;
        options : option_type;
        data : array(1..DATA_LENGTH) of INTEGER;
    end record;

subtype HALF_OCTET is INTEGER range 0..15;
subtype OCTET is INTEGER range 0..255;
subtype ONE_N_FIVE_EIGHTHS_OCTETS is INTEGER range 0..8191;
subtype TWO_OCTETS is INTEGER range 0..65535;
subtype FOUR_OCTETS is INTEGER range 0..4294967296;
```

5.2.5 Event List

The events are drawn from the service primitives specified in section 5.1 above. An event is composed of a service primitive with its parameters and data.

1. SNP_SEND(to_SNP)

2. NULL - Although IP issues no service request, certain conditions within the subnet layer elicit a service response.

5.2.6 Events and Actions

The following section defines the set of possible actions elicited by each event.

EVENT = SNP_SEND(to_SNP)

ACTIONS:

1. SNP_DELIVER Datagram to IP at local destination LD with all of the following properties:

   a. The quality of data transmission is at least equal to the relative levels specified by to_SNP.type_of_service.

OR,

2. no action

EVENT = NULL

ACTIONS:

1. SNP_DELIVER from_SNP indicating the following error condition:

a. error conditions within the subnet layer

6. IP ENTITY SPECIFICATION

This section defines the mechanisms of an IP entity supporting the services provided by the IP service machine. The first subsection motivates the specific mechanisms chosen and describes their operation. The second subsection defines the format and use of the IP header fields. The last subsection specifies an extended state machine representation of the protocol entity.

The implementation of a protocol entity must be robust. Each implementation must expect to interoperate with others created by different individuals. While the goal of this specification is to be explicit about the entity mechanisms, there is always the possibility of differing interpretations. In general, an implementation must be conservative in its sending behavior, and liberal in its receiving behavior. That is, it must be careful to send well-formed datagrams, but must accept any datagram that it can interpret.

6.1 OVERVIEW OF IP MECHANISMS

The IP mechanisms are motivated by the IP services, described in section 2:

- o datagram delivery service
- o virtual network service
- o error reporting service

Each service could be supported by any of a set of mechanisms. The selection of mechanisms is guided by design standards including simplicity, generality, flexibility, and efficiency. The following mechanism descriptions identify the service or services supported, discuss the design criteria used in selection, and explain how the mechanisms work.

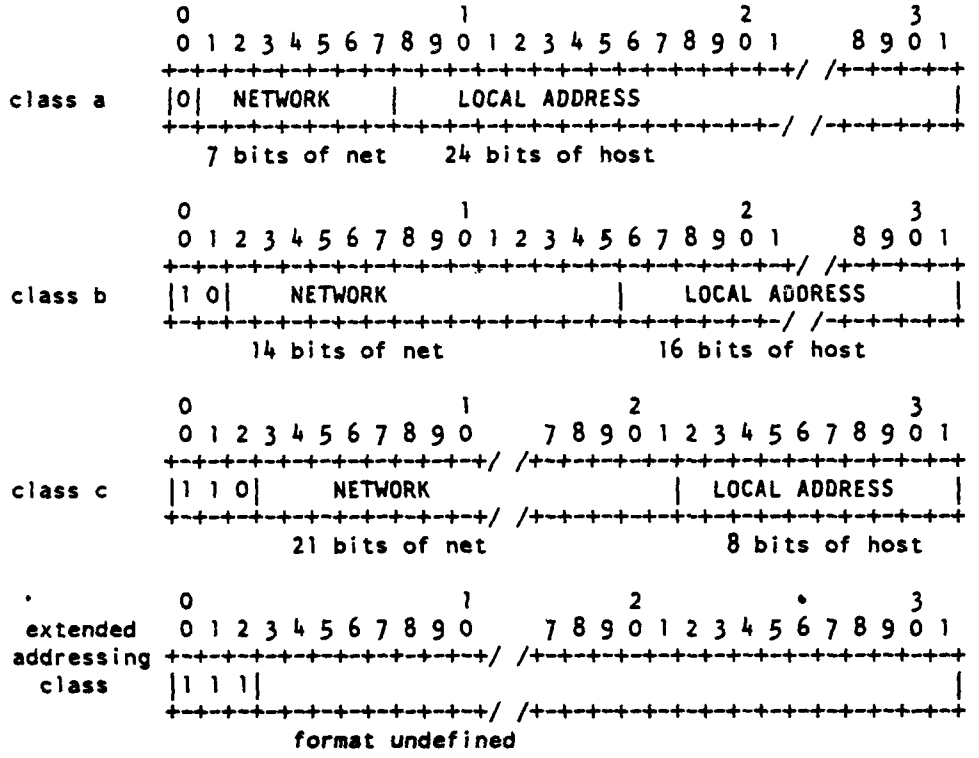
6.1.1 Routing Mechanism

IP contains an adaptive routing mechanism to support the delivery service. The routing mechanism uses the internet addressing scheme and internet topology data to direct datagrams along the best path between source and destination. The mechanism provides routing options for ULPs needing the flexibility to select routes and record routing information.

A distinction is made between names, addresses, and routes. A name indicates the object sought independently of physical location. An address indicates where the object is. A route indicates how to get there. It is the task of the upper layer protocols to map from names to addresses. The internet protocol maps from internet addresses to local subnet addresses to perform routing through the internet. It is the task of lower layer protocols to route the datagram to the appropriate local subnet destination addresses.

Internet addresses have a fixed length of four octets (32 bits). An internet address begins with a network number followed by a local address (called the REST field). To provide for flexibility in assigning addresses to networks and allow for the large number of small to medium sized networks, there are

four formats or classes of internet addresses. These classes are shown in the following diagram:



In "class a", the high order bit is zero, the next 7 bits specify the network, and the last 24 bits specify the local address. In "class b", the high order two bits are one-zero, the next 14 bits are the network and the last 16 bits are the local address. In "class c", the high order three bits are one-one-zero, the next 21 bits are the network and the last 8 bits are the local address. In the extended addressing class, the high order three bits are one-one-one, the next 29 bits have *no* defined format.

The mapping between internet addresses and local net addresses should allow a single physical host to act as several distinct internet hosts. Also, some hosts will have several physical interfaces (i.e. be multi-homed). That is, provision must be made for a host to have several physical interfaces to a subnetwork with each having several logical internet addresses. Examples of address mappings can be found in [9].

To route a datagram, an IP module examines the NETWORK field of the internet address indicating the destination for the datagram. If the network number is the same as the IP module's subnetwork, the module uses the REST field of the internet address to derive the local subnet address of the destination host. If the network number doesn't match, the module determines a local subnet address of a gateway on the best path to the destination subnetwork. In turn,

the gateway IP module derives the next local subnet address to either a host or gateway. In this way, the datagram is relayed through the internet to the destination host.

In a static environment the routing algorithm is straightforward. However, internet topology tends to change due to hardware or software failure, host availability, or heavy traffic load conditions. So, each host and gateway IP along the gateway route also uses its current knowledge of internet topology to make routing decisions.

6.1.1.1 Routing Options IP provides a mechanism, called source routing, to supplement the gateway's independent routing decisions. This mechanism allows an upper layer protocol to influence the gateway route a datagram traverses. The ULP can pass a list of internet addresses, called a source route list, as one of the SEND service request parameters. Each address on the list, except for the last, is an intermediate gateway destination. The last address on the list is the final destination. The source IP module uses its normal routing mechanism to transmit the datagram to the first address in the source route list. Then the gateway IP replaces source route list entry with its own address as known in the environment into which it is forwarding the datagram. Thus, the datagram follows the source route while recording its "inverse" or recorded route.

Two kinds of source routing are provided by IP: loose and strict. With loose source routing, the host and gateway IP modules along the route may use any number of other intermediate gateways to reach the addresses in the source list. With strict source routing, the datagram must travel directly (i.e. through only the directly connected subnetwork indicated by each address) to each address on the source list. When the source route cannot be followed, the source host IP is notified with an error message [12].

For testing or diagnostic purposes, a ULP can acquire a datagram's record route (independently of the source route option) by using the record route mechanism. The sending ULP supplies an empty record route list and indicates that the gateway route is to be recorded in transit. Then, as each gateway IP module on the gateway route relays the datagram, it adds its address as known in the succeeding environment to the record route list. The destination ULP receives the original datagram along with the record route list which, if reversed, provides a source route to the sending ULP. If more gateways are traversed than can be recorded in the list, the additional gateway addresses are not recorded. Problems with the record route option discovered in transit are reported to the source host IP [12].

When using a routing option, the source ULP must provide a large enough route list to accomodate all the routing information expected. The size of a routing option does not change due to adding addresses.

6.1.2 Fragmentation and Reassembly

IP contains a fragmentation mechanism to break a large datagram into smaller datagrams. This is a more general solution for overcoming differences between subnetwork capacity than legislating a restrictive datagram size small enough

for every subnetwork on the internet. This mechanism can be overriden using the "don't fragment" option to prevent fragmentation. IP also contains a reassembly mechanism which reverses the fragmentation to enable delivery of intact data portions.

When an IP module encounters a datagram that is too big to be transmitted through a subnetwork, it applies its fragmentation mechanism. First, the module divides the data portion of the datagram into two or more pieces. The data must be broken on 8-octet boundaries. For each piece, it then builds a datagram header containing the identification, addressing, and options information needed. Fragmentation data is adjusted in the new headers to correspond to the data's relative position within the original datagram. The result is a set of small datagrams, called fragments, each carrying a portion of the data from the original large datagram. Section 6.3.6.3.7 defines the fragmentation algorithm.

Each fragment is handled independently until the destination IP module is reached. The fragments may follow different gateway routes as internet topology and traffic conditions change. They are also subject to further fragmentation if 'smaller-packet' subnetworks are subsequently traversed.

Every IP module must be able to forward a datagram of 68 octets without further fragmentation. This size allows for a header length of up to 60 octets and the minimum data length of 8 octets.

To reassemble fragments into the original datagram, an IP module combines all those received having the same value for the identification, source address, destination address, security, and protocol. IP allocates reassembly resources when a "first-to-arrive" fragment is recognized. Based on the fragmentation data in the fragment's header, the fragment is placed in a reassembly area relative to its position in the original datagram. When all the fragments have been received, the IP module passes the data in its original form to the destination ULP.

All hosts must be prepared to accept datagrams of up to 576 octets (whether they arrive whole or in fragments). It is recommended that hosts send datagrams larger than 576 octets only if they have assurance that the destination is prepared to accept the larger datagrams. The number 576 is selected to allow a reasonable amount of data to be transmitted in addition to the required header information. For example, this size allows a data block of 512 octets plus 64 header octets to fit in a datagram. The maximum internet header size is 60 octets, and a typical internet header is 20 octets, allowing a margin for headers of upper layer protocols.

Because the subnetwork may be unreliable, some fragments making up a complete datagram can be lost. IP uses the "time-to-live" data (explained in Section 6.1.4 below) to set a timer on the reassembly process. If the timer expires before all the fragments have been collected, IP discards the partially reassembled datagram.

Only the destination IP module should perform reassembly. This recommendation is intended to reduce gateway overhead and minimize the chance of

deadlock[16]. However, reassembly by private agreement between gateways is transparent to the rest of the internet and is allowed.

A ULP can prevent its data from being broken into smaller pieces during transmission. IP provides an override mechanism to prohibit fragmentation called "don't fragment." One example use of the don't fragment mechanism is the down line loading of a small host containing only a simple boot strap program to accept data from a datagram, storing it in memory, and executing it.

Any internet datagram marked "don't fragment" cannot be fragmented by an IP module along the gateway route under any circumstances. If an IP module cannot deliver such a datagram to its destination without fragmenting it, the module discards the datagram and returns an error to the source IP [12]. (Please note that fragmentation, transmission, and reassembly at the subnetwork layer is transparent to IP and can be used at any time.)

6.1.3 Checksum

IP assumes the subnetwork layer to be unreliable regardless of the actual subnetwork protocol present. So, IP provides a checksum mechanism supporting the delivery service to protect the IP header from transmission errors. The data portion is not covered by the IP checksum. If IP enforced a data checksum and discarded datagrams with data checksum failures, it could not support applications that require high throughput and can tolerate a low error rate.

An IP module recomputes the checksum each time the IP header is changed. Changes occur in transit during time-to-live reductions, option updates (both explained below), and fragmentation. The checksum is currently a simple one's complement algorithm, and experimental evidence indicates its adequacy. However, the algorithm is provisional and may be replaced by a CRC procedure, depending on future experience.

6.1.4 Time To Live

As mentioned in the routing discussion above, a datagram's transmission path is subject to changes in internet topology and traffic conditions. Inadvertently, a datagram might be routed on a circuitous path to arrive at its destination after a considerable delay. Or, a datagram could loop through the same IP modules without making real progress towards its destination. Such "old datagrams" reduce internet bandwidth and waste processing time.

To prevent these problems, IP provides a mechanism to limit the lifetime of a datagram, called time-to-live. Along with the other sending parameters, a ULP specifies a maximum datagram lifetime in second units. Each IP module on the gateway route decreases the time-to-live value carried in the IP header. If an IP module receives an expired datagram, it discards the datagram. The lifetime limit is in effect until the datagram's data is delivered to the destination ULP. That is, if a datagram is fragmented during transmission, it can still expire during the reassembly process. Section 6.3.4.3 defines the reassembly algorithm use of the time-to-live data.

6.1.5 Type of Service

In support of the virtual network service, the type of service mechanism allows upper layer protocols to select the transmission quality. IP passes the type of service (TOS) command set for service quality to the SNP where it is mapped into subnetwork-specific transmission parameters. Not every subnetwork supports all transmission services, but each SNP on the delivery path should make a best effort to match the available subnet services to the desired service quality. Example mappings of the internet type of service to the actual service provided on networks such as AUTODIN II, ARPANET, SATNET, AND PRNET are given in [9].

The TOS command set includes precedence level, a delay indication, a throughput indication, and a reliability indication. Precedence is a measure of a datagram's importance. A subnetwork may treat high precedence traffic as more important than other traffic by preferentially allocating subnetwork resources especially during time of high load. The sixteen precedence levels begin with the lowest, Routine, and increase through to the two highest levels, Internetwork Control and Network Control. The highest precedence level, Network Control, is intended for use only within a subnetwork. The Internetwork Control level is intended for use by gateway control originators only. The actual use and access to these precedence levels is the responsibility of each subnetwork.

Aside from precedence, the major service choice is a three-way tradeoff between low delay, high reliability, and high throughput. In many networks better performance for one of these parameters is coupled with worse performance for another. Except for very unusual cases, at most two of these three indications should be set. The use of these service quality indications may increase the cost (in some sense) of the service. Section 6.2.15 specifies the legal values of the type of service indicators to be carried in the datagram header.

6.1.6 Data Options

Motivated by the virtual network service, IP provides options to carry certain identification and timing data in a standard manner through the internet. The use of this mechanism by the ULPs is optional, as the name implies, but all options must be supported by each IP implementation.

The data options carry three kinds of information: security, stream identification, and timing. The security data is used by DoD hosts needing to transmit security information throughout the internet in a standard manner. The security information (required if classified, restricted, or compartmented traffic is passed) includes security level, compartments, handling restrictions, and transmission control code. The stream identification option provides a way for a stream identifier to be carried both through stream-oriented, for example SATNET, subnetworks and subnets not supporting the stream concept.

Timing information, in the form of timestamps, is recorded by IP modules as the datagram traverses the internetwork to its destination. The source ULP provides a timestamp list and indicates timing information is to be recorded.

The timestamp can be recorded in one of three formats. The first format requires each gateway IP module on the gateway route to register only its timestamp in the next free list entry. The second format requires each gateway IP to register both its internet address and its timestamp. The third format requires a timestamp to be registered only if the next list entry containing a prespecified internet address matches the gateway IP's address. These formats are specified in Section 6.2.15.

A timestamp is a 32-bit value marking the current time in milliseconds since midnight UT. If the time is not available in milliseconds, or cannot be provided with respect to midnight UT, then any time may be inserted if the high order bit of the timestamp field is set to one, indicating the use of a non-standard value.

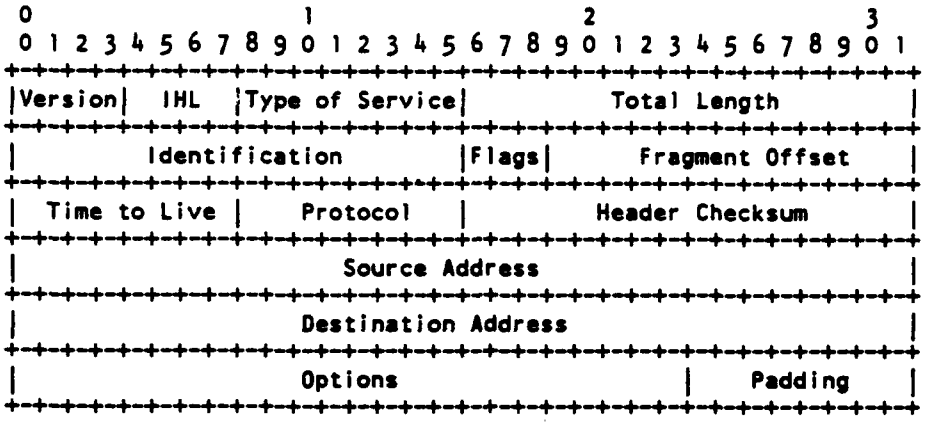
When using the timestamp option, the source ULP must provide a large enough list to accomodate all the timestamp information expected. The size of the option does not change due to adding timestamps. The initial contents of the timestamp list must be zero or internet address/zero pairs. If the timestamp data area is already full (the pointer exceeds the length) the datagram is forwarded without inserting the timestamp, but the overflow count is incremented by one. If there is some room but not enough for a full timestamp to be inserted, or the overflow count itself overflows, the original datagram is considered to be in error and is discarded. In either case an ICMP parameter problem message may be sent to the source host. Errors encountered by the gateway IPs during timestamp processing are reported to the source IP [12].

6.1.7 Error Report Datagrams

The error reporting service motivates a mechanism to generate and process error information. The error mechanism uses the datagram delivery service to transfer the error reports between IP modules.

6.2 MESSAGE FORMAT FOR PEER EXCHANGES

A summary of the contents of the IP header follows:



IP Header Format

Note that each tick mark represents one bit position. Each field description below includes its name, an abbreviation, and the field size. Where applicable, the units, the legal range of values, and a default value appears.

6.2.1 Version

abbrev: VER field size: 4 bits

The Version field indicates the format of the IP header. This document describes version 4.

6.2.2 Internet Header Length

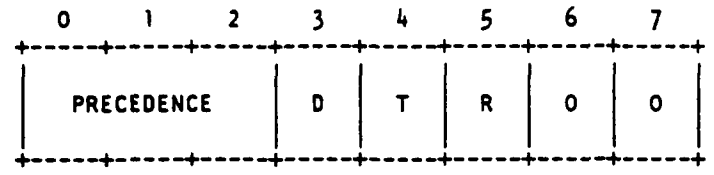
abbrev: IHL field size: 4 bits
units : 4-octet group range : 5 - 15 default : 5

Internet Header Length is the length of the IP header in 32-bit words, and thus points to the beginning of the data. Note that the minimum value for a correct header is 5.

6.2.3 Type of Service

abbrev: TOS field size: 8 bits

The Type of Service field contains the IP parameters describing the quality of service desired for this datagram. Example service mappings for some networks are provided in [11].



Bits 0-2: Precedence
Bit 3: Delay
Bits 4: Throughput
Bits 5: Reliability
Bit 6-7: Reserved for Future Use.

Precedence
111 - Network Control
110 - Internetwork Control
101 - CRITIC/ECP
100 - Flash Override
011 - Flash
010 - Immediate
001 - Priority
000 - Routine

Delay
0 - normal
1 - low

Throughput
0 - normal
1 - high

Reliability
0 - normal
1 - high

6.2.4 Total Length

abbrev: TL field size: 16 bits
units: octets range : 20 - 2**16-1 default: 20

Total Length is the length of the datagram, measured in octets, including header portion and the data portion of the datagram.

6.2.5 Identification

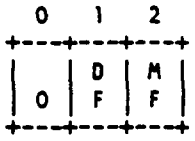
abbrev: ID field size : 16 bits

An identifying value used to associate fragments of a datagram. This value is usually supplied by the sending ULP as an interface parameter. If not, IP generates datagram identifications which are unique for each sending ULP.

6.2.6 Flags

abbrev: none field size : 3 bits

This field contains the control flags "don't fragment", which prohibits IP fragmentation and, "more fragments", which helps to identify a fragment's position in the original datagram.



Bit 0: reserved, must be zero
Bit 1: (DF) 0 = May Fragment, 1 = Don't Fragment.
Bit 2: (MF) 0 = Last Fragment, 1 = More Fragments.

6.2.7 Fragment Offset

abbrev: FO field size : 13 bits
units : 8-octet groups range : 0 - 8191 default : 0

This field indicates the positions of this fragment's data relative to the beginning of the data carried in the original datagram. Both a complete datagram and a first fragment have this field set to zero. Section 6.1.2 describes the fragmentation mechanism.

6.2.8 Time to Live

abbrev : TTL field size : 8 bits
units : seconds range : 0 - 255(=4.25 mins) default : 15

This field indicates the maximum time the datagram is allowed to remain in the internet. If the value of this field drops to zero, the datagram should be destroyed. Section 6.1.4 describes the time-to-live mechanism.

6.2.9 Protocol

abbrev : PROT field size : 8 bits

This field indicates which ULP is to receive the data portion of the datagram. The numbers assigned to common ULPs are avaiable from the DoD Executive Agent for Protocols.

6.2.10 Header Checksum

abbrev : none field size : 16 bits

This field contains the checksum covering the IP header. The checksum mechanism is described in Section 6.1.3.

6.2.11 Source Address

abbrev : source field size : 32 bits

This field contains the internet address of the datagram's source host. Internet address formats are discussed in Section 6.1.1.

6.2.12 Destination Address
abbrev : dest field size : 32 bits

This field contains the internet address of the datagram's destination host. Internet address formats are discussed in Section 6.1.1.

6.2.13 Padding
abbrev : none field size : variable (8 to 24 bits)

The IP header padding is used to ensure that the IP header ends on a 32-bit boundary. The padding field is set to zero.

6.2.14 Options
abbrev : none field size : variable

The option field is variable in length depending on the number and types of options associated with the datagram. The options mechanisms are discussed in Sections 6.1.1 and 6.1.6. Error messages concerning options are specified in [12].

Options have two formats:

a. a single octet of option-type, or

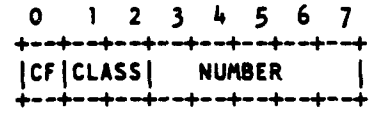
b. a variable length string containing:

1. an option-type octet,

2. an option-length octet - counting the option-type octet and option-length octet as well as the option-data octets, and

3. the actual option-data octets.

The option-type octet is viewed as having 3 fields:



bit 0 - copy flag
0 = not copied, 1 = copied
bits 1-2 - option class
0 = control
1 = reserved for future use
2 = debugging and measurement
3 = reserved for future use
bits 3-7 - option number (defined in the following table)

The following internet options are defined:

CLASS	NUMBER	LENGTH	DESCRIPTION
0	0	-	End of Option list: This option occupies only 1 octet; it has no length octet.
0	1	-	No Operation: This option occupies only 1 octet; it has no length octet.
0	2	11	Security: Used to carry security level, Compartmentation, User Group (TCC), and Handling Restriction Codes compatible with DOD requirements.
0	3	var.	Loose Source Routing: Used to route the datagram based on information supplied by the source.
0	9	var.	Strict Source Routing: Used to route the datagram based on information supplied by the source.
0	7	var.	Record Route: Used to trace the route a datagram takes.
0	8	4	Stream ID: Used to carry the stream identifier.
2	4	var.	Internet Timestamp: Used to accumulate timing information in transit.

6.2.15 Specific Option Definitions

Each option format is defined below. "Option type" indicates the value of the option-type octet, and "length" indicates the value of the length-octet if appropriate.

6.2.15.1 End of Option List

option type : 0 option length : N/A

This one octet option marks the end of the option list when it does not coincide with the four-octet boundary indicated by the IP header length. This field is used following the last option, not the end of each option, and need only be used if the last option would not otherwise coincide with the end of the IP header. This option may be introduced or deleted upon fragmentation as needed.

6.2.15.2 No Operation

option type : 1 option length : N/A

This option may be used between options, for example, to align the beginning of a subsequent option on a 32-bit boundary. This option may be introduced or deleted upon fragmentation as needed.

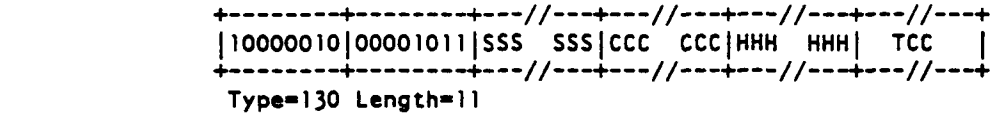
6.2.15.3 Security

option type : 130 option length : 11

This option (required if classified, restricted, or compartmented traffic is passed) provides a way for hosts to send Security level, Compartmentation,

Handling Restriction Codes and User Groups (TCC) parameters through subnetworks in a standard manner. This option must be copied on fragmentation. This option appears at most once in a datagram.

The format for this option is as follows:



Security (S field)
length : 16 bits

This field specifies one of 16 levels of security, eight of which are reserved for future use.

00000000 00000000 - Unclassified
11110001 00110101 - Confidential
01111000 10011010 - EFTO
10111100 01001101 - MMMM
01011110 00100110 - PROG
10101111 00010011 - Restricted
11010111 10001000 - Secret
01101011 11000101 - Top Secret
00110101 11100010 - (Reserved for future use)
10011010 11110001 - (Reserved for future use)
01001101 01111000 - (Reserved for future use)
00100100 10111101 - (Reserved for future use)
00010011 01011110 - (Reserved for future use)
10001001 10101111 - (Reserved for future use)
11000100 11010110 - (Reserved for future use)
11100010 01101011 - (Reserved for future use)

Compartments (C field)
length = 16 bits

This field contains an all zero value when the information transmitted is not compartmented. Other values for the compartments field may be obtained from the Defense Intelligence Agency.

Handling Restrictions (H field)
length = 16 bits

The values for the control and release markings are alphanumeric digraphs and are defined in the Defense Intelligence Agency Manual DIAM 65-19, "Standard Security Markings".

Transmission Control Code (TCC field)
length = 24 bits

This field provides a means to segregate traffic and define controlled communities of interest among subscribers. The TCC values are trigraphs, and are available from HQ DCA Code 530.

6.2.15.4 Loose Source and Record Route
option type : 131 option length : variable

The loose source route option provides a way for the source ULP of a datagram to supply routing information to be used by IP modules along the gateway route. At the same time, the "inverse" route is recorded in the option field. This option must be copied on fragmentation. It appears at most once in a datagram.

The option begins with the option type code. The second octet is the option length which includes the option type octet, the length octet, the pointer octet, and the source route list. The third octet is a pointer into the route data indicating the octet which begins the next source address to be processed. The pointer is relative to this option, and its smallest legal value is 4.

A loose source route list is composed of one or more internet addresses identifying intermediate gateways to be visited in transit. Each internet address is 4 octets long. When a gateway in the source route list is visited, the gateway address (as known in the environment into which the datagram is being forwarded) replaces that list entry.

The size of this option is fixed by the source. It cannot change to accommodate additional information. The routing options are described in Section 6.1.1.1.

6.2.15.5 Strict Source and Record Route
option type : 137 option length : variable

The strict source route option provides a way for the source ULP of a datagram to name the exact set of IP modules to be visited along the gateway route. At the same time, the "inverse" route is recorded in the option field. This option must be copied on fragmentation. It appears at most once in a datagram.

The option begins with the option type code. The second octet is the option length which includes the option type octet, the length octet, the pointer octet, and the source route list. The third octet is a pointer into the route data indicating the octet which begins the next source address to be processed. The pointer is relative to this option, and its smallest legal value is 4.

A strict source route list is composed of one or more internet addresses identifying the gateways to be visited in transit. The datagram must visit exactly the gateways listed, traversing only the directly connected subnetworks indicated in the route list addresses. When a gateway in the source

route list is visited, the gateway address (as known in the environment into which the datagram is being forwarded) replaces that list entry.

The size of this option is fixed by the source. It cannot change to accommodate additional information. Routing options are described in Section 6.1.1.1.

6.2.15.6 Record Route
option type : 7 option length : variable

The record route option provides a way to record a datagram's gateway route. This option must be copied on fragmentation. It appears at most once in a datagram.

The option begins with the option type code. The second octet is the option length which includes the option type code, the length octet, and the return route list. The third octet is a pointer into the route data indicating the octet which begins the next area to store a route address. The pointer is relative to this option, and the smallest legal value for the pointer is 4.

A record route list is composed of a series of internet addresses. Each internet address is 4 octets long. The source ULP provides a route list with zero value entries. As each gateway is visited in transit, it registers its address in the next free entry (indicated by the pointer). When the pointer is greater than the length, the record route list is full; no additional addresses are recorded, even if more are visited before arriving at the destination.

The size of this option is fixed by the source. It cannot change to accommodate additional information. The routing options are described in Section 6.1.1.1.

6.2.15.7 Stream Identifier
option type : 136 option length : 4

This option provides a way for 16-bit stream identifiers to be carried through the internet for use by subnetworks supporting the stream concept such as the SATNET. The stream identifier appears in the third and fourth octets of the option. This option must be copied on fragmentation. It appears at most once in a datagram.

6.2.15.8 Internet Timestamp
option type : 68 option length : variable

This option allows timing information to be gathered as a datagram travels through the internet to its destination. This option is not copied upon fragmentation and so appears only in the first fragment. This option may appear at most once in a datagram.

The first octet is the option type. The second octet is the length of the option including the option type octet, the length octet, the pointer octet, the overflow/flag octet, and each timestamp or address/timestamp pair. The third octet is a pointer into the timestamp list identifying the octet beginning the space for the next timestamp. The pointer is relative to the beginning of this option; its smallest legal value is 5.

The fourth octet is shared by overflow and format flag information. The first 4 bits record the number of IP modules that could not register timestamps due to lack of space. The second 4 bits indicate the format of the timestamp list:

0 - time stamps only, stored in consecutive 32-bit words
1 - each timestamp is preceded with the internet address of the registering entity
2 - reserved for future use
3 - the internet address fields are prespecified by the source ULP. An IP module only registers its timestamp if its address matches the next one in the list.

The size of this option is fixed by the source. It cannot change to accommodate additional information. The internet timestamp option is described in Section 6.1.6.

6.3 EXTENDED STATE MACHINE SPECIFICATION OF IP ENTITY

The IP entity is specified with an extended state machine made up of a set of states, a set of transitions between states, and a set of input events causing the state transitions. The following specification is made up of a machine instantiation identifier, a state diagram, a state vector, data structures, an event list, and a correspondence between events and actions. In addition, an extended state machine has an initial state whose values are assumed at state machine instantiation.

6.3.1 Machine Instantiation Identifier

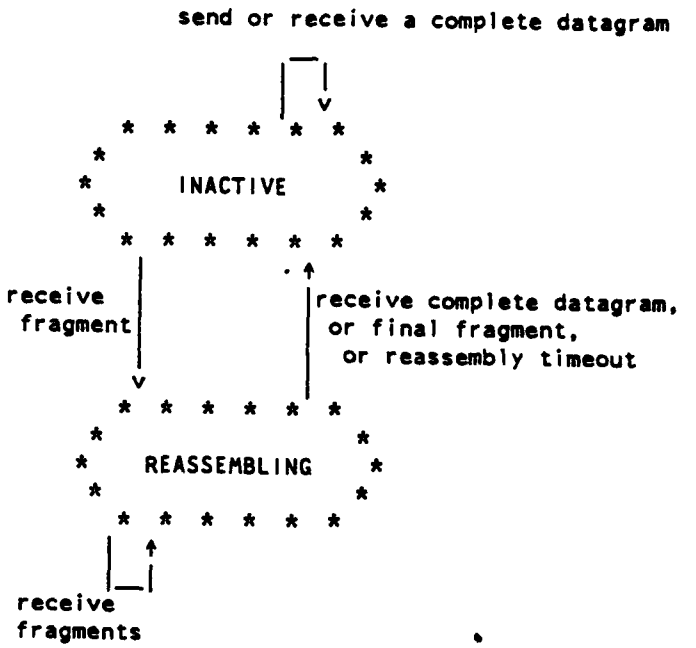
Each datagram is an independent unit. Therefore, one state machine instance exists for each datagram. Each state machine is uniquely named by the four values:

- o source address
- o destination address
- o protocol
- o identification

These values are drawn from parameters of the interaction primitives specified in Sections 3.1 and 5.1.

6.3.2 State Diagram

The following diagram depicts a simplified IP state machine.



6.3.3 State Vector

A state vector consists of the following elements :

- o STATE NAME = (inactive, reassembling)
- o REASSEMBLY RESOURCES = control information and storage needed to reassemble fragments into the original datagram, including:
  - reassembly map : a representation of each 8-octet unit of data and its relative location within the original datagram.
  - timer : value of the reassembly timer in unit seconds ranging from 0 to 255.
  - total data length : size of the data carried in datagram being reassembled.
  - header : storage area for the header portion of the datagram being reassembled.
  - data : storage area for the data portion of the datagram being reassembled.

A state machine's initial state is INACTIVE with unused reassembly resources.

6.3.4 Data Structures

The IP state machine references certain data areas corresponding to the state vector, and each interaction primitive : SEND, DELIVER, SNP_SEND, and SNP_DELIVER. For clarity in the events and actions section, data structures are declared in Ada for these data areas. However, a data structure may be partially typed or completely untyped where specific formats or data types are implementation dependent.

6.3.4.1 state vector The definition of an IP state vector appears in Section 6.3.3 above. A state_vector structure is declared as:

```
state_vector : state_vector_type;

type state_vector_type is
  record
    state_name : (INACTIVE, REASSEMBLING);
    reassembly_map
    timer
    total_data_length
    header
    data
  end record;
```

6.3.4.2 from ULP The from_ULP structure holds the interface parameters and data associated with the SEND primitive, as specified in Section 3.1.1. The from_ULP structure is declared as:

```
from_ULP : from_ULP_type;

type from_ULP_type is
  record
    source_addr
    destination_addr
    protocol
    type_of_service is
      record
          precedence
          delay
          throughput
          reliability
      end record;
    identifier
    time_to_live
    dont_fragment
    length
    data
    options
  end record;
```

6.3.4.3 to ULP The to_ULP structure holds interface parameters and data associated with the DELIVER primitive, as specified in Section 3.1.2. The to_ULP structure is declared as:

```
to_ULP : to_ULP_type;

type to_ULP_type is
  record
    source_addr
    destination_addr
    protocol
    type_of_service is
      record
          precedence
          delay
          throughput
          reliability
      end record;
    length
    data
    options
    error
  end record;
```

6.3.4.4 from SNP The from_SNP structure holds the interface parameters and datagram associated with the SNP_DELIVER primitive, as specified in Section 5.2.2. The from_SNP structure is declared as:

```
type from_SNP_type is
  record
     local_destination_addr
     dtgm: datagram_type;
     error
  end record;
```

The dtgm element is itself a structure as specified below.

6.3.4.5 to SNP The to_SNP structure holds the data and parameters associated with the SNP_SEND primitive specified in Section 5.2.1. The to_SNP structure is declared as:

```
type to_SNP_type is
  record
    local_destination_addr
    type_of_service_indicators
    length
    dtgm: datagram_type;
  end record;
```

The dtgm element is itself a structure as specified below. specified below.

6.3.4.6 dtgm A dtgm structure holds a datagram made up of a header portion and a data portion as specified in Section 6.2. A dtgm structure is declared as:

```
type datagram_type is
   record
     version : HALF_OCTET;
     header_length : HALF_OCTET;
     type_of_service : OCTET;
     total_length : TWO_OCTETS;
     identification : TWO_OCTETS;
     dont_frag_flag : BOOLEAN;
     more_frag_flag : BOOLEAN;
     fragment_offset : ONE_N_FIVE_EIGHTHS_OCTETS;
     time_to_live : OCTET;
     protocol : OCTET;
     header_checksum : TWO_OCTETS;
     source_addr : FOUR_OCTETS;
     destination_addr : FOUR_OCTETS;
     options : OPTION_TYPE;
     data : array(1..DATA_LENGTH) of INTEGER;
  end record;

subrecord HALF_OCTET is INTEGER range 0..15;
subrecord OCTET is INTEGER range 0..255;
subrecord ONE_N_FIVE_EIGHTHS_OCTETS is INTEGER range 0..8191;
subrecord TWO_OCTETS is INTEGER range 0..65535;
subrecord FOUR_OCTETS is INTEGER range 0..4294967296;
subrecord OPTION_TYPE is zero or more of the following:
                         security;
                         loose source routing;
                         strict source routing;
                         record route;
                         stream identifier;
                         internet timestamp;
```

6.3.5 Event List

The event list is made up of the interaction primitives specified in Sections 3.1 and 5.1 and the services provided by the execution environment defined in Section 7. The following list defines the set of possible events in an IP state machine:

a. SEND from ULP - A ULP passes interface parameters and data to IP for delivery across the internet (see 3.1.1.1).

b. SNP_DELIVER from SNP - SNP passes to IP a datagram received from subnetwork protocol (see 5.1.2.1).

c. TIMEOUT - The timing mechanism provided by the execution environment indicates a previously specified time interval has elapsed (see 7.2).

6.3.6 Events and Actions

This section is organized in three parts. The first part contains a decision table representation of state machine events and actions. The decision tables are organized by state; each table corresponds to one event.

The second part specifies the decision functions appearing at the top of each column of a decision table. These functions examine attributes of the event and the state vector to return a set of decision results. The results become the elements of each column.

The third part specifies action procedures appearing at the right of every row. Each row of the decision table combines the decision results to determine appropriate event processing. These procedures specify event processing algorithms in detail.

6.3.6.1 Events and Actions Decision Tables

STATE = INACTIVE

Event: SEND from ULP

Actions:

ULP params valid?	where dest?	need to frag?	can frag?	
NO	d	d	d	error to ULP(PARAM_PROBLEM)
YES	ULP	d	d	local delivery
YES	REMOTE	NO	d	build&send
YES	REMOTE	YES	NO	error to ULP(CAN'T_FRAG)
YES	REMOTE	YES	YES	fragment&send

Comments:

A ULP passes data to IP for internet delivery. IP validates the interface parameters, determines the destination, and dispatches the ULP data to its destination.

Legend

d = "don't care" condition

STATE = INACTIVE

Event: SNP_DELIVER from SNP

Actions:

checksum valid?	SNP params valid?	TTL valid?	where to?	a frag?	icmp checksum?	
NO	d	d	d	d	d	discard
YES	NO	d	d	d	d	error to source(PARAM_PROBLEM)
YES	YES	NO	d	d	d	error to source(EXPIRED_TTL)
YES	YES	YES	ULP	NO	d	remote delivery
YES	YES	YES	ULP	YES	d	reassemble;STATE:=REASSEMBLING
YES	YES	YES	ICMP	NO	NO	discard
YES	YES	YES	ICMP	NO	YES*	analyze
YES	YES	YES	ICMP	YES	d	reassemble;STATE:=REASSEMBLING
YES	YES	YES	REMOTE	d	d	error to source(HOST_UNREACH)

Comments:
The SNP has delivered datagram from another IP. IP validates the datagram header, and either delivers the data from a complete datagram to its destination within the host or begins reassembly for a datagram fragment.

Legend
d = "don't care" condition

STATE = REASSEMBLING

Event: SNP_DELIVER from SNP

Actions:

Legend
d = "don't care" condition

checksum valid?	SNP params valid?	TTL valid?	where to?	a frag?	reass done?	icmp checksum?	
NO	d	d	d	d	d	d	discard
YES	NO	d	d	d	d	d	error_to_source(PARAM_PROBLEM)
YES	YES	NO	d	d	d	d	error_to_source(EXPIRED_TTL)
YES	YES	YES	ULP	NO	d	d	remote_delivery;state:=INACTIVE
YES	YES	YES	ULP	YES	NO	d	reassemble
YES	YES	YES	ULP	YES	YES	d	reass_delivery;state:=INACTIVE
YES	YES	YES	ICMP	NO	d	NO	discard
YES	YES	YES	ICMP	NO	d	YES	analyze;state:=INACTIVE
YES	YES	YES	ICMP	YES	NO	d	reassemble
YES	YES	YES	REMOTE	d	d	d	error_to_source(HOST_UNREACH)

Comment:
The SNP has delivered a datagram associated to an earlier received datagram fragment. IP validates the header and either continues the reassembly process with the datagram fragment or delivers the data from the completed datagram to its destination within the host.

Event: TIMEOUT

Actions: reassembly timeout; state:=INACTIVE

Comment:
The time-to-live period of the datagram being reassembled has elapsed. The incomplete datagram is discarded; the source IP is informed.

6.3.6.2 Decision Table Functions The following functions examine information contained in interface parameters, interface data, and the state vector to make decisions. These decisions can be thought of as further refinements of the event and/or state. The return values of the functions represent decisions made. The decision functions appear in alphabetical order.

6.3.6.2.1 a frag? The a_frag function examines certain fields in an incoming datagram's header to determine whether the datagram is a fragment of a larger datagram.

The data effects of this algorithm are:

- Data examined only:

  from_SNP.dtgm.fragment_offset
  from_SNP.dtgm.more_frag_flag

- Return values:

  NO - the datagram has not been fragmented
  YES - the datagram is a part of a larger datagram

```
if ((from_SNP.dtgm.fragment_offset = 0)      --contains the beginning
    and (from_SNP.dtgm.more_frag_flag = 0)) --and the end of the data

then return NO   --therefore it is an unfragmented datagram

else return YES; --otherwise it contains only a portion of the data
                 --and is a fragment.
```

6.3.6.2.2 can frag? The can_frag function examines the don't fragment flag of the interface parameters allowing fragmentation.

The data effects of this function are:

- Data examined only:

  from_ULP.dont_fragment

- Return values:

  NO - don't fragment flag is set, preventing fragmentation
  YES -don't fragment flag is NOT set, to allow fragmentation

```
if (from_ULP.dont_fragment = TRUE)
then return NO
else return YES
end if;
```

6.3.6.2.3 checksum valid? The checksum_valid function examines an incoming datagram's header to determine whether it is free from transmission errors.

The data effects of this function are:

- Data examined only:

```
        from_SNP.dtgm.version              from_SNP.dtgm.fragment_offset
        from_SNP.dtgm.header_length        from_SNP.dtgm.time_to_live
        from_SNP.dtgm.type_of_service      from_SNP.dtgm.protocol
        from_SNP.dtgm.total_length         from_SNP.dtgm.source_addr
        from_SNP.dtgm.identification       from_SNP.dtgm.destination_addr
        from_SNP.dtgm.dont_frag_flag       from_SNP.dtgm.options
        from_SNP.dtgm.more_frag_flag
```

- Return values:

```
        NO   -- checksum did not check, indicating header fields
                contain errors
        YES  -- checksum was consistent


--The checksum algorithm is the 16-bit one's complement
--of the one's complement sum of all 16-bit words in
--the IP header.  For purposes of computing the checksum,
--the checksum field is set to zero.

    --implementation dependent action
```

6.3.6.2.4 icmp checksum? The icmp_checksum function computes the checksum of the ICMP control message carried in the data portion of the incoming datagram.

The data effects of this procedure are:

- Data examined:

  from_SNP.dtgm.data

- Return values:

  NO -- checksum did not check indicating the control message contains errors
  YES -- checksum was consistent

```
--The checksum algorithm is the 16-bit one's complement of
--the one's complement sum of all 16-bit words
--in ICMP control message.  For purposes of computing the checksum,
--the checksum field (octets 2-3) is set to zero.

      --implementation dependent action
```

6.3.6.2.5 need to frag? The need_to_frag function examines the interface parameters and data from a ULP to determine whether the data can be transmitted as a single datagram or must be transmitted as two or more datagram fragments.

The data effects of this function are:

- Data examined only:

  from_ULP.length
  from_ULP.options

- Return values:

  NO - one datagram is small enough for the subnetwork
  YES - datagram fragments are needed to carry the data

```
--Compute the datagram's length based on the length of data,
--the length of options, and the standard datagram header size.

if (( from_ULP.length + (number of bytes of option data) + 20 )
        > maximum transmission unit of the local subnetwork )
then return YES
else return NO;
end if;
```

6.3.6.2.6 reass done? The reass_done function examines the incoming datagram and the reassembly resources to determine whether the final fragment has arrived to complete the datagram being reassembled.

The data effects of this function are:
Data examined only:

state_vector.reassembly_map
state_vector.total_data_length
from_SNP.dtgm.total_length
from_SNP.dtgm.more_frag_flag
from_SNP.dtgm.header_length

- Return values:

NO - more fragments are needed to complete reassembly
YES - this is the only fragment needed to complete reassembly

```
--The total data length of the original datagram, as computed from
--"tail" fragment, must be known before completion is possible.

  if (state_vector.total_data_length = 0)
  then
    --Check incoming datagram for "tail."

      if (from_SNP.dtgm.more_frag_flag = FALSE)
      then
        --Compute total data length and see if data in
        --this fragment fills out reassembly map.

          if (state_vector.reassembly_map from 0 to
               (((from_SNP.dtgm.total_length -          --total data
                  (from_SNP.dtgm.header_length*4)+7)/8) --  length
              +7)/8  is set )
          then return YES;
          end if;
      else
        --Reassembly cannot be complete if total data length unknown.
           return NO;
      end if;

    else --Total data length is already known.  See if data
         --in this fragment fills out reassembly map.

         if ( all reassembly map from 0 to
                 (state_vector.total_data_length+7)/8 is set)
         then return YES;  --final fragment
         else return NO;   --more to come
         end if;
    end if;
```

6.3.6.2.7 SNP params valid? The SNP_params_valid function examines the interface parameters and the datagram received from the local subnetwork protocol to see if all values are within legal ranges and no errors have occurred.

The data effects of this function are:

- Data examined only:

from_SNP.dtgm.version	from_SNP.dtgm.protocol
from_SNP.dtgm.header_length	other information/errors from SNP
from_SNP.dtgm.total_length	

- Return values:

NO - some value or values are illegal or an error has occurred

YES - examined values are within legal ranges and no errors have occurred

```
if (  --The current IP header version number is 4.
    (from_SNP.dtgm.version != 4)

      --The minimal IP header is 5 32-bit units in length.
  or (from_SNP.dtgm.header_length < 5)

      --The smallest legal datagram contains only a header and is
      --20 octets in length.
  or (from_SNP.dtgm.total_length < 20)

      --The legal protocol identifiers are
        available from the DoD Executive Agent for Protocols.
  or (from_SNP.dtgm.protocol is not one of the acceptable identifiers)

    )

 then return NO

 elseif (any implementation dependent values received from the
          SNP are illegal or indicate error conditions)
    then return NO
    else return YES;   --Otherwise, all values look good.
    endif;
endif;
```

6.3.6.2.8 TTL valid? The TTL_valid function examines the IP header time-to-live field of an incoming datagram to determine whether the datagram has exceeded its allowed lifetime.

The data effects of this function are:

- Data examined only:

  from_SNP.dtgm.time_to_live

- Return values:

  NO - the datagram has expired
  YES - the datagram has some life left in it

```
--Decrement from_SNP.dtgm.time_to_live field by the maximum
--of either the amount of time elapsed since the last IP module
--handled this datagram (if known) or one second.

 if (( from_SNP.dtgm.time_to_live
       - maximum(number of seconds elapsed since last IP, 1))
     <= 0 )
 then return NO
 else return YES;
```

6.3.6.2.9 ULP params valid? The ULP_params_valid function examines the interface parameters received from a ULP to see if all values are within legal ranges and desired options are supported.

The data effects of this function are:

- Data examined only:

  from_ULP.time_to_live
  from_ULP.options

- Return values:

  NO - some value is illegal or a desired option is not supported.

  YES - examined values are within legal ranges and desired options can be supported.

```
if (
     --The time-to-live value must be greater than zero to
     --allow IP to transmit it at least once.
     (from_ULP.time_to_live < 0 )

  or --The options requested are inconsistent.
        --implementation dependent action

  or --Other implementation dependent values are invalid.
        --implementation dependent action
   )

then return NO

else return YES;

end if;
```

6.3.6.2.10 where dest? The where_dest function determines the destination of an outgoing datagram by examining the destination address supplied by the ULP.

The data effects of this function are:

- Data examined only:

  from_ULP.destination_addr

- Return values:

  ULP - destination is an upper layer protocol at this location
  REMOTE - destination is some remote location

```
--Examine the destination address field of the datagram header.

  if (from_SNP.dtgm.destination_addr != this site's address)
  then return REMOTE
  else return ULP;
  end if;
```

6.3.6.2.11 where to? The where_to function determines the destination of the incoming datagram by examining the address fields and options fields of the datagram header.

The data effects of this function are:

- Data examined only:

```
from_SNP.dtgm.destination_addr
from_SNP.dtgm.protocol
from_SNP.dtgm.options
```

- Return values:

```
ULP - destination is an upper layer protocol at this location
ICMP  - destination is this IP module because the datagram
        carries an ICMP control message
REMOTE - destination is some remote location
```

```
--The source route influences the datagram's gateway route.

  if ((from_SNP.dtgm.options contains the source routing option)
       (and all source route list addresses have not been visited))
  then return REMOTE;
  endif;

--Examine the destination address field of the datagram header.

  if (from_SNP.dtgm.destination_addr != this site's address)
  then
      --It's destined for another site.
       return REMOTE
  else
      --It's destined for this site.
       if (from_SNP.dtgm.protocol = the ICMP protocol identifier)
       then return ICMP
       else return ULP;
       end if;
  end if;
```

6.3.6.3 Decision Table Action Procedures The following action procedures represent the set of actions an IP state machine should perform in response to a particular event and internal state. These procedures have been organized and designed for clarity and are intended as guidelines. Although implementors may in fact reorganize for better performance, the data effects of the resulting implementations must not differ from those specified below.

6.3.6.3.1 analyze The analyze procedure examines datagrams containing ICMP control messages from other IP modules. In general, error handling is implementation dependent. However, guidelines are provided to identify classes of errors and suggest appropriate actions. The errors and error formats are defined in [12].

The data effects of this procedure are:

- Data examined:

  from_SNP.dtgm.protocol
  from_SNP.dtgm.data

- Data modified:

  implementation dependent

For simplicity, it is assumed that the data area can be accessed as a byte array.

```
--Examine the first octet in the data portion to identify the
--error type and subsequent format.

begin

case from_SNP.dtgm[1] of

     when 3 =>  --Destination Unreachable Message

       --The errors in the "unreachable" class
       --should be passed to the ULP indicating data delivery
       --to the destination is unlikely if not impossible.
       --The second octet identifies what level was unreachable.

        case from_SNP.dtgm[2] of

          when 0 =>  --net unreachable

          when 1 =>  --host unreachable

          when 2 =>  --protocol unreachable

          when 3 =>  --port unreachable

          when 4 =>  --fragmentation needed and don't fragment set

          when 5 =>  --source route failed

        end case;

     when 11 =>  --Time Exceeded Message
```

```
        --The "time-out" errors are usually not passed
        --to the ULP but should be recorded for network
        --monitoring uses.

        case from_SNP.dtgm[2] of

          when 0 =>  --Time to live exceeded in transit

          when 1 =>  --Fragment reassembly time exceeded

        end case;

      when 12 =>  --Parameter Problem Message
        --This error is generated by a gateway IP to indicate
        --a problem in the options field of a datagram header.
        --Octet 5 contains a pointer which identifies
        --the octet of the original header containing the error.

      when 4  =>  --Source Quench Message
        --This message indicates that a datagram has been
        --discarded for congestion control.  The ULP should
        --be informed so that traffic can be reduced.

      when 5  =>  --Redirect Message
        --This message should result in a routing table update
        --by the IP module.  Octets 5-8 contain the new value
        --for the routing table. It is not passed to the ULP.

      when 8  =>  --Echo Datagram
        --Refer to [12].

      when 0  =>  --Echo Reply Datagram
        --Refer to [12].

      when 13 =>  --Timestamp Datagram
        --Refer to [12].

      when 14 =>  --Timestamp Reply Datagram
        --Refer to [12].

      when 15 =>  --Information Request Message
        --Refer to [12].

      when 16 =>  --Information Reply Message
        --Refer to [12].

end case;
```

6.3.6.3.2 build&send The build&send procedure builds an outbound datagram in the to_SNP structure from the interface parameters and data in from_ULP and passes it to the SNP for transmission across the subnet.

The data effects of this procedure are:

- Data examined:

from_ULP.source_addr	from_ULP.time_to_live
from_ULP.destination_addr	from_ULP.dont_fragment
from_ULP.protocol	from_ULP.options
from_ULP.type_of_service	from_ULP.length
from_ULP.identifier	from_ULP.data

- Data modified:

to_SNP.dtgm	to_SNP.type_of_service_indicators
to_SNP.length	to_SNP.local_destination_addr

```
--Fill in each IP header field with information from from_ULP or
--standard values.

    to_SNP.dtgm.version := 4;      --Current IP version is 4.
    to_SNP.dtgm.type_of_service.indicators := from_ULP.type_of_service;
    to_SNP.dtgm.identification := from_ULP.identifier;  --If ID is not given
                                                        --by ULP, the IP must
                                                        --supply its own.
    to_SNP.dtgm.dont_frag_flag := from_ULP.dont_fragment;
    to_SNP.dtgm.more_frags_flag := 0;
    to_SNP.dtgm.fragment_offset := 0;
    to_SNP.dtgm.time_to_live := from_ULP.time_to_live;
    to_SNP.dtgm.protocol := from_ULP.protocol;
    to_SNP.dtgm.source_addr := from_ULP.source_addr;
    to_SNP.dtgm.destination_addr := from_ULP.destination_addr;
    to_SNP.dtgm.options := from_ULP.options;
    to_SNP.dtgm.header_length := 5 + (number of bytes of option data)/4;
    to_SNP.dtgm.total_length := (to_SNP.dtgm.header_length)*4
                                          + (from_ULP.length);

--Call compute_checksum to compute and set the checksum.

    compute_checksum;


--And, fill in the data portion of the datagram.

    to_SNP.dtgm.data[0..from_ULP.length -1]  := from_ULP.data[0..
                                                    from_ULP.length-1];
--Set the type of service and length fields for the SNP.

    to_SNP.type_of_service_indicators := to_SNP.dtgm.type_of_service;
```

```
    to_SNP.length := to_SNP.dtgm.total_length;

 --Call the route procedure to determine a local destination
 --from the internet destination address supplied by the ULP.

    route;

 --Request the execution environment to pass the contents of to_SNP
 --to the local subnetwork protocol for transmission.

    TRANSFER to_SNP to the SNP.
```

NOTE: The format of the from_ULP elements is unspecified allowing an implementor to assign data types for the interface parameters. If those data types differ from the IP header types, the assignment statements above become type conversions.

6.3.6.3.3 compute checksum The compute_checksum procedure calculates a checksum value for a datagram header so that transmission errors can be detected by a destination IP.

The data effects of this procedure are:

- Data examined:

to_SNP.dtgm.version	to_SNP.dtgm.fragment_offset
to_SNP.dtgm.header_length	to_SNP.dtgm.time_to_live
to_SNP.dtgm.type_of_service	to_SNP.dtgm.protocol
to_SNP.dtgm.total_length	to_SNP.dtgm.source_addr
to_SNP.dtgm.identification	to_SNP.dtgm.destination_addr
to_SNP.dtgm.dont_frag_flag	to_SNP.dtgm.options
to_SNP.dtgm.more_frag_flag	

- Data modified:

  to_SNP.dtgm.header_checksum

```
  --The checksum algorithm is the 16-bit one's complement of
  --the one's complement sum of all 16-bit words
  --in the IP header.  For purposes of computing the checksum,
  --the checksum field is set to zero.

       --implementation dependent action
```

6.3.6.3.4 compute icmp checksum The compute_icmp_checksum procedure computes the checksum of the ICMP control message carried in the data portion of an outgoing datagram. See [12] for a description of ICMP.

The data effects of this procedure are:

- Data examined:

  to_SNP.dtgm.data

- Data modified:

  to_SNP.dtgm.data[2-3]

```
--The checksum algorithm is the 16-bit one's complement of
--the one's complement sum of all 16-bit words
--in ICMP control message.  For purposes of computing the checksum,
--the checksum field (octets 2-3) is set to zero.

      --implementation dependent action
```

6.3.6.3.5 error to source The error_to_source procedure formats and returns an error report to the source of an erroneous or expired datagram.

The data effects of this procedure are:

- Parameters:

```
error_param : (PARAM_PROBLEM, EXPIRED_TTL,
               PROTOCOL_UNREACH);
```

- Data examined:

```
from_SNP.dtgm
```

- Data modified:

```
to_SNP.dtgm          to_SNP.local_destination_addr
to_SNP.length        to_SNP.type_of_service_indicators
```

```
--Format and transmit an error datagram to the source IP.

to_SNP.dtgm.version          :=  4;       --standard IP version
to_SNP.dtgm.header_length    :=  5;       --standard header size
to_SNP.dtgm.type_of_service  :=  0;       --routine service quality
to_SNP.dtgm.identification   :=  select new value;
to_SNP.dtgm.more_frag_flag   :=  FALSE;
to_SNP.dtgm.dont_frag_flag   :=  FALSE;
to_SNP.dtgm.fragment_offset  :=  0;
to_SNP.dtgm.time_to_live     :=  60;      --or value large enough to
                                          --allow delivery
to_SNP.dtgm.protocol         :=  this number will be assigned by
                                 DoD Executive Agent for Protocols;
to_SNP.dtgm.source_addr      :=  from_SNP.dtgm.destination_addr;
to_SNP.dtgm.destination_addr :=  from_SNP.dtgm.source_addr;

--The data section carries the ICMP control message.
--The first octet identifies the message type, the remaining
--octets carry related information.  Refer to [12] for
--individual message type formats.

  case error_param of

     where PARAM_PROBLEM =>
       to_SNP.dtgm.data[0] := 12;    --ICMP type = Parameter Problem
       to_SNP.dtgm.data[1] := 0;     --Code = problem with option
       to_SNP.dtgm.data[4] := position of error octet;

     where EXPIRED_TTL =>
       to_SNP.dtgm.data[0] := 11;    --ICMP type = Time Exceeded
       to_SNP.dtgm.data[1] := 0;     --Code = TTL exceed in transit

     where PROTOCOL_UNREACH =>
```

```
            to_SNP.dtgm.data[0] := 3;     --ICMP type = Dest. Unreachable
            to_SNP.dtgm.data[1] := 2;     --Code = protocol unreachable

        end case;

    --The bad datagram's header plus the first 64 bytes of its
    --data section (a total of "N" octets) is copied in following
    --the ICMP information.

        to_SNP.dtgm.data[8..N+3] := from_SNP.dtgm.data[0..N-1];
        to_SNP.dtgm.total_length := from_SNP.header_length*4 + N + 8;
        compute_icmp_checksum;

    --Compute checksum, determine the route for the error datagram,
    --the type of service indicators, and the datagram size for the SNP.

        compute_checksum;
        to_SNP.type_of_service_indicators := 0;
        to_SNP.length := to_SNP.dtgm.total_length;
        route;

    --Request the execution environment to pass the contents of to_SNP
    --to the local subnet protocol for transmission.

        TRANSFER to_SNP to the SNP.
```

6.3.6.3.6 error to ULP The error_to_ULP procedure returns an error report to a ULP which has passed invalid parameters or has requested a service that cannot be provided.

The data effects of this procedure are:

- Parameters:

```
error_param : (PARAM_PROBLEM, CAN'T_FRAGMENT,
               NET_UNREACH, PROTOCOL_UNREACH,
               PORT_UNREACH);
```

- Data examined:

  implementation dependent

- Data modified:

  to_ULP.error
  implementation dependent parameters

```
--The format of error reports to a ULP is implementation
--dependent.  However, included in the report should be
--a value indicating the type of error, and some information
--to identify the associated data or datagram.

  to_ULP.error := error_param;
  --implementation dependent action
```

6.3.6.3.7 fragment&send The fragment&send procedure breaks data that is too big to be transmitted through the subnetwork as a single datagram into smaller pieces for transmission in several datagrams. Normally, hosts do not send datagrams too big to go through their own network.

The data effects of the procedure are:

- Data examined only:

```
from_ULP.source_addr              from_ULP.length
from_ULP.destination_addr         from_ULP.data
from_ULP.protocol                 from_ULP.options
from_ULP.identifier               from_ULP.time_to_live
from_ULP.dont_fragment
```

- Data modified:

```
to_SNP.dtgm          to_SNP.type_of_service_indicators
to_SNP.length
```

- Local variables:

```
number_of_fragments -- number of small datagrams created from
                       user data

data_per_fragment -- the number of octets in each small datagram

number_frag_blocks -- the number of 8-octet blocks in each small
                      datagram
data_in_last_frag -- the number of octets in the last datagram

j -- loop counter for each fragment generated
```

```
--Compute the fragmentation variables.

--The amount of data per fragment equals the max datagram size less
--the length of the datagram header.
   data_per_fragment   := maximum subnet transmission unit
                          - (20 + number of bytes of option data);

   number_frag_blocks  := data_per_fragment/8;

   number_of_fragments := (from_ULP.length + (data_per_fragment-1))
                          / data_per_fragment;

   data_in_last_frag := from_ULP.length modulo data_per_fragment;

--Create the first fragment and transmit it to the SNP.

   to_SNP.dtgm.version := 4;
   to_SNP.dtgm.header_length := 5 + (number bytes of option data/4);
   to_SNP.dtgm.total_length := to_SNP.dtgm.header_length
```

```
                                                + data_per_fragment;
      to_SNP.dtgm.identificatin := from_ULP.identifier;
      to_SNP.dtgm.dont_frag_flag := from_ULP.dont_fragment; --this will be false
      to_SNP.dtgm.more_frag_flag := TRUE;
      to_SNP.dtgm.fragment_offset := 0;
      to_SNP.dtgm.time_to_live := from_ULP.time_to_live;
      to_SNP.dtgm.protocol := from_ULP.protocol;
      to_SNP.dtgm.source_addr := from_ULP.source_addr;
      to_SNP.dtgm.destination_addr := from_ULP.destination_addr;
      to_SNP.dtgm.options := from_ULP.options;
      to_SNP.dtgm.data[0..data_per_fragment-1] :=
                                from_ULP.data[0..data_per_fragment-1];

   --Set the datagram's header checksum field.
      compute_checksum;

   --Call route to determine the subnetwork address of the destination.
      route;

   --Also set the length and type of service indicators.
      to_SNP.length := to_SNP.dtgm.total_length;
      to_SNP.type_of_service_indicators := to_SNP.dtgm.type_of_service;

   --Request the execution environment to pass the first fragment
   --to the SNP.
      TRANSFER to_SNP to the local subnetwork protocol.


   --Format and transmit successive fragments.

     for j in 1..number_of_fragments-1 loop

        --The header fields remain the same as in the first fragment,
        --EXCEPT for:

          if ("copy" flag present in any options)  --most significant bit
                                                     of option octet

          then --put ONLY "copy" options into options fields and
               --adjust length fields accordingly.

               to_SNP.dtgm.options := (options with "copy" flag);
               to_SNP.dtgm.header_length := 5 +
                                        (number of copy options octets/4);

          else --only standard datagram header present

               to_SNP.dtgm.header_length := 5;

          endif;

        --Append data and set fragmentation fields.
```

```
        if (j /= number_of_fragments-1)

        then --middle fragment(s)

          to_SNP.dtgm.more_frag_flag := TRUE;
          to_SNP.dtgm.fragment_offset := j*number_frag_blocks;
          to_SNP.dtgm.total_length := to_SNP.dtgm.header_length
                                        + data_per_fragment;
          to_SNP.dtgm.data[0..data_per_fragment-1] :=
                                from_ULP.data[j*data_per_fragment..
                                 (j*data_per_fragment + data_per_fragment-1)];

        else --last fragment

          to_SNP.dtgm.more_frag_flag := FALSE;
          to_SNP.dtgm.fragment_offset := j*number_frag_blocks;
          to_SNP.dtgm.total_length := to_SNP.dtgm.header_length*4
                                                + data_in_last_frag;
          to_SNP.dtgm.data[0..data_in_last_frag-1] :=
                               from_ULP[j*data_per_fragment..
                                 (j*data_per_fragment+ data_in_last_frag-1)];
        end if;

      --Call checksum to set the datagram's header checksum field.
        checksum;

      --Call route to determine the subnetwork address of the destination.
        route;

      --Also set the length and type of service indicators.
        to_SNP.length := to_SNP.dtgm.total_length;
        to_SNP.type_of_service_indicators := to_SNP.dtgm.type_of_service;

      --Request the execution environment to pass this fragment
      --to the SNP.
        TRANSFER to_SNP to the local subnetwork protocol.

    end loop;
```

A fragmentation algorithm may vary according to implementation concerns but every algorithm must meet the following requirements:

1. A datagram must not be fragmented if dtgm.dont_frag_flag is true.

2. Data must be broken on 8-octet boundaries.

3. The minimum fragment size is 68 octets.

4. The first fragment must contain all options carried by the original datagram, except padding and no-op octets.

5. The security, source routing, and stream identification options (i.e. marked with "copy" flag, MSB in option octet) must be carried by all fragments, if present in the original datagram.

6. The first fragment must have to_SNP.dtgm.fragment_offset set to zero.

7. All fragments, except the last, must have to_SNP.dtgm.more_frag_flag set true.

8. The last fragment must have the to_SNP.dtgm.more_frag_flag set false.

6.3.6.3.8 local delivery The local_delivery procedure moves the interface parameters and data in the from_ULP structure to the to_ULP structure and delivers it to an in-host ULP.

The data effects of this procedure are:

- Data examined:

from_ULP.destination_addr	from_ULP.length
from_ULP.source_addr	from_ULP.data
from_ULP.protocol	from_ULP.options
from_ULP.type_of_service	

- Data modified:

to_ULP.source_addr	to_ULP.length
to_ULP.destination_addr	to_ULP.data
to_ULP.protocol	to_ULP.options
to_ULP.type_of_service	

```
--Move the interface parameters and data from the input
--structure, from_ULP, directly to the output structure, to_ULP,
--for delivery to a local ULP.

   from_ULP.destination_addr := to_ULP.destination_addr;
   from_ULP.source_addr      := to_ULP.source_addr;
   from_ULP.protocol         := to_ULP.protocol;
   from_ULP.type_of_service  := to_ULP.type_of_service;
   from_ULP.length           := to_ULP.length;
   from_ULP.data             := to_ULP.data;
   from_ULP.options          := to_ULP.options;

--Request the execution environment to pass the contents of to_SNP
--to the local subnet protocol for transmission.

   TRANSFER to_ULP to to_ULP.protocol.
```

6.3.6.3.9 reassemble The reassemble procedure reconstructs an original datagram from datagram fragments. The data effects of this procedure are:

- Data examined:

  from_SNP.dtgm

- Data modified:

  state_vector.reassembly_map
  state_vector.timer
  state_vector.total_data_length
  state_vector.header
  state_vector.data

- Local variables:

  j -- loop counter

  data_in_frag -- the number of octets of data in received fragment

```
data_in_frag := (from_SNP.dtgm.total_length-from_SNP.dtgm.header_length*4);

--Put data in its relative position in the data area of the state vector.

  state_vector.data[from_SNP.dtgm.fragment_offset*8..
                    from_SNP.dtgm.fragment_offset*8+data_in_frag] :=
                                  from_SNP.dtgm.data[0..data_in_frag-1];

--Fill in the corresponding entries of the reassembly map representing
--each 8-octet unit of received data.

  for j in (from_SNP.dtgm.fragment_offset)..
           (from_SNP.dtgm.fragment_offset + data_in_frag + 7)/8) loop

    state_vector.reassembly_map[j] := 1;
  end loop;

--Compute the total datagram length from the "tail-end" fragment.

  if (from_SNP.dtgm.more_frag_flag = FALSE)
  then state_vector.header.total_data_length :=
                        from_SNP.dtgm.fragment_offset*8 + data_in_frag;
  end if;

--Record the header of the "head-end" fragment.

  if (from_SNP.dtgm.fragment_offset = 0)
  then state_vector.header := from_SNP.dtgm;
  end if;

--Reset the reassembly timer if its current value is less than the
--time-to-live field of the received datagram.
```

```
state_vector.timer := maximum(
                from_SNP.dtgm.time_to_live, state_vector.timer);
```

A reassembly algorithm may vary according to implementation concerns, but each one must meet these requirements:

1. Every destination IP module must have the capacity to receive a datagram 576 octets in length, either in one piece or in fragments to be reassembled.

2. The header of the fragment with from_SNP.dtgm.fragment_offset equal to zero (i.e. the "head-end" fragment) becomes the header of the reassembling datagram.

3. The total length of the reassembling datagram is calculated from the fragment with from_SNP.dtgm.more_frag_flag equal to zero (i.e. the "tail-end" fragment).

4. A reassembly timer is associated with each datagram being reassembled. The current recommendation for the initial timer setting is 15 seconds. Note that the choice of this parameter value is related to the buffer capacity available and the data rate of the transmission medium. That is, data rate multiplied by timer value equals reassembly capacity (e.g.10Kb/s X 15secs = 150Kb).

5. As each fragment arrives, the reassembly timer is reset to the maximum of state_vector.reassembly_resources.timer and from_SNP.dtgm.time_to_live in the incoming fragment.

6. The first fragment of the datagram being reassembled must contain all options, except padding and no-op octets.

7. The source_addr, destination_addr, protocol, and identifier of the first fragment received must be recorded. All subsequent fragments's source_addr, destination_addr, protocol, and identifier will be compared against those recored. Those fragments which do not match will be discarded.

8. As each fragment arrives, the security and precedence fields, if avaiable, must be checked. If the security level of the fragment does not match the security level of the connection or if the precedence level of the fragment does not match the precedence level of the connection, the datagram being assembled is discarded. Also, an error datagram is returned to the source IP to report the "mismatched security/precedence" error.

9. If the reassembly timer expires, the datagram being reassembled is discarded. Also, an error datagram is returned to the source IP to report the "time exceeded during reassembly" error.

6.3.6.3.10 reassembled delivery The reassembled_delivery procedure decomposes the datagram that has been reassembled in the state vector into interface parameters and data, then delivers them to a ULP.

The data effects of this procedure are:

- Data examined:

```
state_vector.header.destination_addr
state_vector.header.source_addr
state_vector.header.protocol
state_vector.header.type_of_service
state_vector.header.header_length
state_vector.header.total_length
state_vector.header.options
state_vector.data
```

- Data modified:

```
to_ULP.destination_addr        to_ULP.length
to_ULP.source_addr             to_ULP.data
to_ULP.protocol                to_ULP.options
to_ULP.type_of_service
```

```
to_ULP.destination_addr  := state_vector.header.destination_addr;
to_ULP.source_addr       := state_vector.header.source_addr;
to_ULP.protocol          := state_vector.header.protocol;
to_ULP.type_of_service   := state_vector.header.type_of_service;
to_ULP.length            := state_vector.header.total_length;
                              - state_vector.header.header_length*4;
to_ULP.options           := state_vector.header.options;
to_ULP.data              := state_vector.data;
```

6.3.6.3.11 reassembly timeout The reassembly_timeout procedure generates an error datagram to the source IP informing it of the datagram's expiration during reassembly.

The data effects of the procedure are:

- Data examined:

  state_vector.header
  state_vector.data

- Data modified:

  to_SNP.dtgm to_SNP.type_of_service_indicators
  to_SNP.length to_SNP.header_length

```
  --Format and transmit an error datagram to the source IP.

  to_SNP.dtgm.version         :=  4;       --standard IP version
  to_SNP.dtgm.header_length   :=  5;       --standard header size
  to_SNP.dtgm.type_of_service :=  0;       --routine service quality
  to_SNP.dtgm.identification  :=  new value selected;
  to_SNP.dtgm.more_frag_flag  :=  FALSE;
  to_SNP.dtgm.dont_frag_flag  :=  FALSE;
  to_SNP.dtgm.fragment_offset :=  0;
  to_SNP.dtgm.time_to_live    :=  60;
  to_SNP.dtgm.protocol        :=  this number will be assigned by
                                  the DoD Executive Agent for Protocols;
  to_SNP.dtgm.source_addr     :=  state_vector.header.destination_addr;
  to_SNP.dtgm.destination_addr := state_vector.header.source_addr;

--If the fragment received is the first fragment, then the
--data section carries the ICMP error message, the header of the
--timed-out datagram, and its first 64 bytes of data.

  to_SNP.dtgm.data[0] := 12;    --ICMP type = Time Exceeded
  to_SNP.dtgm.data[1] := 1;     --Code = fragment reassembly timeout

--Copy in the timed-out datagram's header plus the first
--64 bytes of its data section (assumed to be of length "N").

  to_SNP.dtgm.data[8..N+3] := state_vector[0..N-1];
  to_SNP.dtgm.total_length := to_SNP.header_length*4 + N + 8;
  compute_icmp_checksum;

--Compute datagram's header checksum, determine the route for the datagram,
--the type of service indicators, and the datagram size for the SNP.

  compute_checksum;
  to_SNP.type_of_service_indicators := 0;
```

```
    to_SNP.length := to_SNP.dtgm.total_length;
    route;

  --Request the execution environment to pass the contents of to_SNP
  --to the local subnet protocol for transmission.

    TRANSFER to_SNP to the SNP.
```

6.3.6.3.12 remote delivery The remote_delivery procedure decomposes a datagram arriving from a remote IP into interface parameters and data and delivers them to the destination ULP.

The data effects of this procedure are:

- Data examined:

from_SNP.dtgm.source_addr	from_SNP.dtgm.total_length
from_SNP.dtgm.destination_addr	from_SNP.dtgm.header_length
from_SNP.dtgm.protocol	from_SNP.dtgm.data
from_SNP.dtgm.type_of_service	from_SNP.dtgm.options

- Data modified:

to_ULP.destination_addr	to_ULP.length
to_ULP.source_addr	to_ULP.data
to_ULP.protocol	to_ULP.options
to_ULP.type_of_service	

```
to_ULP.destination_addr  :=  from_SNP.dtgm.destination_addr;
to_ULP.source_addr       :=  from_SNP.dtgm.source_addr;
to_ULP.protocol          :=  from_SNP.dtgm.protocol;
to_ULP.type_of_service   :=  from_SNP.dtgm.type_of_service;
to_ULP.length            :=  from_SNP.dtgm.total_length -
                                 from_SNP.dtgm.header_length*4;
to_ULP.data              :=  from_SNP.dtgm.data;
to_ULP.options           :=  from_SNP.dtgm.options;
```

NOTE: The format of the to_ULP elements is unspecified allowing an implementor to assign data types for the interface parameters. If those data types differ from the IP header types, the assignment statements above become type conversions.

6.3.6.3.13 route The route procedure examines the destination address and options fields of an outbound datagram in to_SNP to determine a local destination address.

The data effects of this procedure are:

- Data examined:

  to_SNP.dtgm.destination_addr
  to_SNP.dtgm.options

- Data modified:

  to_SNP.local_destination_addr
  to_SNP.dtgm.options

The procedure:

```
     if (to_SNP.dtgm.options includes timestamp)
     then
       if (the next timestamp field in to_SNP.dtgm.options.timestamp
             is available)
       then
            --The timestamp or address/timestamp pair is inserted in
            --the next field in to_SNP.dtgm.options.timestamp.
       end if;
     end if;

    if (the network id field of destination matches the network id
          of the local subnet protocol )
    then
         --Translate the REST field of destination into the subnetwork
         --address of the destination on this subnet.
           --implementation dependent action
    else

       if (to_SNP.dtgm.options includes security)
       then
           --Find the appropriate gateway with security level equal to
           --the security level of to_SNP.dtgm.options.security.  If
           --none exists send error message.
       end if;

       if (to_SNP.dtgm.options includes loose source and record routing)
       then
          if (the network id field of next gateway in to_SNP.dtgm.option.
                loose_source matches the network of the local subnet
                protocol)
          then
               --The gateway address (as known in the environment into
               --which the datagram is being forwarded) replaces the
               --the network id field of next gateway in to_SNP.dtgm
               --.options.loose_source
```

```
            end if;
         end if;

         if (to_SNP.dtgm.options includes strict source and record routing)
         then
            if (the network id field of next gateway in to_SNP.dtgm.option.
                  strict_source matches the network of the local subnet
                  protocol)
            then
                 --The gateway address (as known in the environment into
                 --which the datagram is being forwarded) replaces the
                 --the network id field of next gateway in to_SNP.dtgm
                 --.options.strict_source.
            else
                 --The datagram cannot be forwarded and error message
                 --sent.
            end if;
         end if;

         if (to_SNP.dtgm.options includes record routing)
         then
            if (the next record route field in to_SNP.dtgm.options.record_
                   routing is available)
            then
                 --The gateway address (as known in the environment into
                 --which the datagram is being forwarded) replaces the
                 --next record route field in to_SNP.dtgm.options.record_
                 --routing.
            end if;
          end if;
       end if;


   --Set the local destination interface parameter.

      to_SNP.local_destination_addr := (subnetwork address found above);
```

7. EXECUTION ENVIRONMENT REQUIREMENTS

This section describes the facilities required of an execution environment for proper implementation and operation of the Internet Protocol. Throughout this document, the environmental model portrays each protocol as an independent process. Within this model, the execution environment must provide two facilities: interprocess communication and timing.

7.1 INTERPROCESS COMMUNICATION

The execution environment must provide an interprocess communication facility to enable independent processes to exchange variable-length units of information, called messages. For IP's purpcses, the IPC facility is not required to preserve the order of messages.

IP uses the IPC facility to exchange interface parameters and data with upper layer protocols across its upper interface and the subnetwork protocol across the lower interface. Sections 3 and 5 specify these interfaces.

7.2 TIMING

The execution environment must provide a timing facility that maintains a real-time clock with units no coarser than 1 millisecond. A process must be able to set a timer for a specific time period and be informed by the execution environment when the time period has elapsed. A process must also be able to cancel a previously set timer.

Two IP mechanisms use the timing facility. The internet timestamp carries timing data in millisecond units. The reassembly mechanism uses timers to limit the lifetime of a datagram being reassembled. In the mechanism specification this facility is called TIMEOUT.

8. GLOSSARY

Destination
An IP header field containing an internet address indicating where a datagram is to be sent.

datagram
A self-contained package of data carrying enough information to be routed from source to destination without reliance on earlier exchanges between source or destination and the transporting subnetwork.

datagram fragment
The result of fragmenting a datagram, also simply referred to as a fragment. A datagram fragment carries a portion of data from the larger original, and a copy of the original datagram header. The header fragmentation fields are adjusted to indicate the fragment's relative position within the original datagram.

datagram service
A datagram, defined above, delivered in such a way that the receiver can determine the boundaries of the datagram as it was entered by the source. A datagram is delivered with non-zero probability to the desired destination. The sequence in which datagrams are entered into the subnetwork by a source is not necessarily preserved upon delivery at the destination.

DF
Don't Fragment flag: An IP header field that when set true prohibits an IP module from fragmenting a datagram to accomplish delivery.

fragmentation
The process of breaking the data within a datagram into smaller pieces and attaching new internet headers to form smaller datagrams.

Fragment Offset
A field in the IP header marking the relative position of a datagram fragment within the larger original datagram.

gateway
A device, or pair of devices, which interconnect two or more subnetworks enabling the passage of data from one subnetwork to another. In this architecture, a gateway usually contains an IP module, a Gateway-to-Gateway Protocol (GGP) module, and a subnetwork protocol module (SNP) for each connected subnetwork.

header
Collection of control information transmitted with data between peer entities.

host
A computer which is a source or destination of messages from the point of view of the communication subnetwork.

ICMP

Internet Control Message Protocol, the collection of error conditions and error message formats exchanged by IP modules in both hosts and gateways.

Identification
An IP header field used in reassembling fragments of a datagram.

IHL
Internet Header Length: an IP header field indicating the number of 32-bit words making up the internet header.

Internet address
A four octet (32 bit) source or destination address composed of a Network field and a REST field. The latter usually contains a local subnetwork address.

internet datagram
The package exchanged between a pair of IP modules. It is made up of an IP header and a data portion.

local address
The address of a host within a subnetwork. The actual mapping of an internet address onto local subnetwork addresses is quite general, allowing for many to one mappings.

local subnetwork
The subnetwork directly attached to host or gateway.

MF
More Fragments flag: an IP header field indicating whether a datagram fragment contains the end of a datagram.

module
An implementation, usually in software, of a protocol or other procedure.

MTU
Maximum Transmission Unit: a subnetwork dependent value which indicates the largest datagram that a subnetwork can handle.

octet
An eight bit byte.

Options
The optional set of fields at the end of the IP header used to carry control or routing data. An Options field may contain none, one, or several options, and each option may be one to several octets in length. The options allow ULPs to customize IP's services. The options are also useful in testing situations to carry diagnostic data such as timestamps.

packet
The unit of data transmitted by a packet-switched network. A packet usually contains nested control information and data from the upper layer protocols using the subnetwork.

packet network
A network based on packet-switching technology. Messages are split into small units (packets) to be routed independently on a store and forward basis. This approach pipelines packet transmission to effectively use circuit bandwidth.

Padding
An IP header field, an octet in length, inserted after the last option field to ensure that the data portion of a datagram begins on a 32-bit word boundary. The Padding field value is zero.

Protocol
An internet header field used to identify the upper layer protocol that is the source and destination of the data within an IP datagram.

Precedence
One of the service quality parameters provided by the type of service mechanism. Precedence is a relative measure of datagram importance. This parameter can be set to one of five levels: routine, priority, immediate, flash, or flash override. It appears as a three-bit field within the Type of Service field in the IP header.

reassembly
The process of piecing together datagram fragments to reproduce the original large datagram. Reassembly is based on fragmentation data carried in their IP headers.

Reliability
One of the service quality parameters provided by the type of service mechanism. The reliability parameter can be set to one of four levels: lowest, lower, higher, or highest. It appears as a two bit field within the Type of Service field in the IP header.

reliability
A quality of data transmission defined as guaranteed, ordered delivery.

Rest
The three-octet field of the internet address usually containing a local address.

segment
The unit of data exchanged by TCP modules. This term may also be used to describe the unit of exchange between any transport protocol modules.

Source
An IP header field containing the internet address of the datagram's point of origin.

stream delivery service
The special handling required for a class of volatile periodic traffic typified by voice. The class requires the maximum acceptable delay to be only slightly larger than the minimum propagation time, or requires the allowable variance in packet interarrival time to be small.

SNP
SubNetwork Protocol: the protocol residing in the subnetwork layer below IP which provides data transfer through the local subnet. In some systems, an adaptor module must be inserted between IP and the subnetwork protocol to reconcile their dissimilar interfaces.

TCP
Transmission Control Protocol: a transport protocol providing connection-oriented, end-to-end reliable data transmission in packet-switched computer subnetworks and internetworks.

TCP segment
The unit of data exchanged between TCP modules (including the TCP header).

Total Length
An IP header field containing the number of octets in an internet datagram, including both the IP header and the data portion.

Type of Service
An IP header field containing the transmission quality parameters: precedence level, reliability level, speed level, resource trade-off (precedence vs. reliability), and transmission mode (datagram vs. stream). This field is used by the type of service mechanism which allows ULPs to select the quality of transmission for a datagram through the internet.

ULP
Upper Layer Protocol: any protocol above IP in the layered protocol hierarchy that uses IP. This term includes transport layer protocols, presentation layer protocols, session layer protocols, and application programs.

user
A generic term identifying a process or person employing a protocol. In IP's case, this term may describe a transport protocol, a presentation layer protocol, a session layer protocol, or an application program.

Version
An IP header field indicating the format of the IP header.

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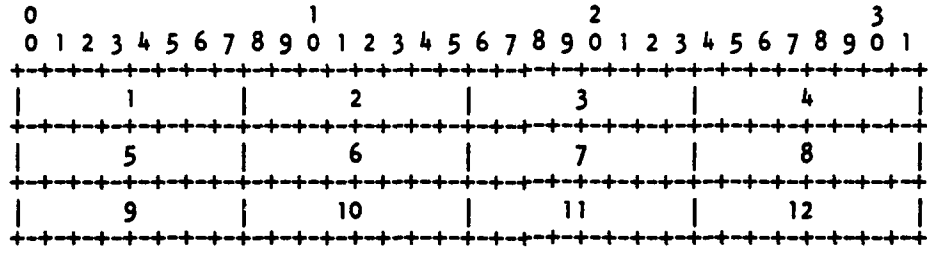
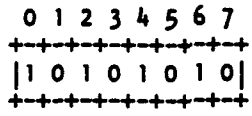
APPENDIX A - DATA TRANSMISSION ORDER

The order of transmission of the header and data described in this document is resolved to the octet level. Whenever a diagram shows a group of octets, the order of transmission of those octets is the normal order in which they are read in English. For example, in the following diagram the octets are transmitted in the order they are numbered.



Transmission Order of Octets

Whenever an octet represents a numeric quantity, the left most bit in the diagram is the high order or most significant bit. That is, the bit labeled 0 is the most significant bit. For example, the following diagram represents the value 170 (decimal).



Significance of Bits

Similarly, whenever a multi-octet field represents a numeric quantity, the left most bit of the whole field is the most significant bit. When a multi-octet quantity is transmitted the most significant octet is transmitted first.

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